

EFFECT OF CARBOHYDRATE AND NITROGEN
SOURCE ON THE UTILIZATION OF
SUGARCANE DIETS

By

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To my wife, Flora, our children, parents
and all those dedicated to the cause of educating others

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A 133-day feedlot trial was conducted with 36 yearling steers to compare sugarcane based diets fed with either molasses/cottonseed meal, molasses/urea or corn meal/urea. Sugarcane comprised 70% of the diet dry matter (DM) while urea supplied 50% of nitrogen in diets containing urea. The daily gains of steers fed either molasses/cottonseed meal or corn meal/urea were higher than those of the steers offered molasses/urea diet ($P < .05$). Dry matter intakes were similar. Steers fed the molasses/urea diet had a 28% higher ($P > .05$) DM intake to gain ratio than those fed the other two diets.

Six digestibility and nitrogen balance trials were conducted using diets similar to those used in the feedlot trial. Twelve yearling steers were used in a cross-over design. The diets contained 10.4, 10.6 and 11.2% crude protein (DM basis) for the molasses/cottonseed meal, molasses/urea and corn meal/urea diets, respectively. Steers were on the diets for 21 days and total fecal and urine

collections were made during the last seven days. Dry matter intake by steers offered the molasses/urea diet was lower than that of steers given molasses/cottonseed meal ($P < .02$), but similar to that of steers fed corn meal/urea diet. Digestibilities for DM and organic matter were highest for steers fed molasses/urea diet ($P < .05$ and $P < .03$, respectively), but those for the other two diets were similar. The digestibilities of crude fiber, neutral detergent fiber, acid detergent fiber, cellulose and lignin were similar for all dietary treatments.

Nitrogen intake was the lowest for the molasses/urea diet ($P < .05$), but similar for molasses/cottonseed meal and corn meal/urea diets. Crude protein digestibility was lower for the molasses/cottonseed diet than for the remaining two diets ($P < .03$). Urinary nitrogen excretion was similar ($P > .10$) for all dietary treatments. The digested nitrogen retained (%) and nitrogen balance were not different ($P > .08$ and $P > .07$, respectively). There were no differences ($P > .05$) in any rate of passage parameters. Propionic acid was higher ($P < .05$) in the rumen fluid of steers fed molasses/urea (26%) than for those fed molasses/cottonseed meal (21.2%) or corn meal/urea (20.5%). Rumen pH was the lowest for the corn meal/urea meal diet ($P < .03$), but similar for the other two diets.

CHAPTER I INTRODUCTION

Low animal productivity is almost synonymous with the tropical and subtropical regions of the world, most of which are developing countries. The extreme dry and wet climatic patterns characteristic of this region result in inefficient utilization of forage, the feed upon which most domestic ruminants depend. The region has approximately 50% of the world's cattle, horses, mules and asses, 75-80% of the goats, buffaloes and camels, and 30-35% of swine, sheep and poultry; yet milk production and growth of cattle is only 10-25% of what is acceptable in the temperate regions (McDowell, 1972). Available animals for meat production are also low, being one sixth to one third of the figures for the temperate zone.

Among the constraints of livestock production in the subtropical and tropical regions, inadequate nutrition of the animals is the major one. This has been a result of both natural causes such as rainfall distribution, and unnatural ones like the destruction of the natural grasslands through overgrazing. As livestock statistics indicate, the challenge to animal production in these regions is not to increase animal numbers but to achieve optimum production per animal using available resources. Priority should be given to the improvement of the quantity and quality of animal feed to ensure some degree of animal production during the critical periods of the year. Depending on the tropical or subtropical area being considered, the problem of inadequate nutrition could either be quantitative (semi-arid and arid

areas), qualitative (wet, hot regions), or both (wet, dry tropics). Quality is decreased by rapid maturity of forages resulting in reduced palatability and digestibility, whereas quantity is lowered by lack of precipitation for often more than several months in a year. The acute undernutrition during the dry season results in the loss of most of the weight gained during the preceding wet period. In view of this, animal and forage scientists have directed their efforts at improving the quality and utilization of crop residues, pasture improvement and forage conservation. So far, these efforts have had variable successes with respect to adaptation of technologies developed and/or improved animal production in the tropical areas; therefore, the search for better feed resources and technologies is still continuing.

There is growing emphasis on feeding sugarcane (Saccharum officinarum) to cattle in tropical and subtropical countries. Sugarcane offers an attractive alternative for feeding animals during periods of feed scarcity because, unlike other forage crops, sugarcane appears to be generally unlimited by both quantitative and qualitative factors. Dry matter yields from sugarcane are very high, often exceeding 40 tons per hectare (Preston et al., 1976) and its quality does not change with maturity (Pate, 1979). Its digestibility usually ranges from 60-65% (Montpellier and Preston, 1977; Ferreiro and Preston, 1977). The main constraint of feeding sugarcane to cattle is its low crude protein content, averaging 2% of the dry matter in the mature cane. When sugarcane is fed without supplemental protein, animal growth responses are normally negative, changing to slight gains when supplemented with urea (Ferreiro et al., 1977). Even the use of traditional protein supplements or concentrates in sugarcane

based diets has resulted in variable animal responses. However, rice polishings have produced growth responses in cattle fed sugarcane and urea (Preston, 1977). Lack of dramatic animal responses to nitrogen supplementation in the form of non-protein nitrogen (NPN) prompted Leng and Preston (1976) to postulate that sugarcane/urea diets were limited by their ability to supply essential amino acids and glucose precursors at the metabolic level. Improved animal performance with some supplements like rice polishings was, therefore, explained in terms of bypass nutrients leading to an increase in the amounts of amino acids and glucose absorbed from the lower alimentary canal. Such a proposition is consistent with findings from feeding rice polishings or fishmeal, both of which show appreciable degrees of resistance to ruminal degradation and their particle sizes are such that they permit flow from the reticulo-rumen.

Even though research has shown that natural proteins are usually better than NPN in promoting animal production with most conventional rations, their widespread use in developing countries is still low due to high prices and scarcity. Therefore, the feasibility of feeding a low protein forage such as sugarcane would be enhanced by the use of inexpensive sources of nitrogen such as urea and other NPN compounds. Likewise, cereal grains are in short supply in most of the developing countries. Only livestock enterprises like poultry and swine can be based on the use of cereals, while ruminants would have to depend largely on forages. The widespread cultivation of sugarcane and the production of its by-product, molasses, in most of the tropical regions, combined with the availability of NPN sources provide an ideal situation for intensified investigations into their use for

animal production. Hence, the objectives of this study were to determine the effects of different dietary energy and nitrogen sources on nutrient digestibility, rate of passage, nitrogen metabolism and performance of steers fed a basal diet of sugarcane. Specific comparisons were made between (1) molasses and corn meal as energy sources in a diet containing a high level of urea, and (2) urea and cottonseed meal as crude protein supplements.

CHAPTER II LITERATURE REVIEW

Sugarcane

Sugarcane Feeding to Cattle

Although the organized planting of sugarcane for sugar extraction dates from 1520 (Barnes, 1964), emphasis on sugarcane feeding to cattle did not start until during the last decade. Interest in feeding sugarcane to cattle probably resulted from lack of feeds of reasonable quality during certain periods of the year in the tropical and subtropical regions of the world. The main advantages of sugarcane over other tropical forages are its high dry matter yields under relatively low management conditions and maintenance of high levels of readily fermentable carbohydrates for several months after reaching maturity. Sugarcane can be fed as either whole plant, chopped, silage or grazed. Grazing requires considerable care and planning to avoid killing the cane plant (Bregger and Kidder, 1959). Unlike fresh sugarcane, ensiled sugarcane harvested at comparable maturities decreased in digestibility with increasing maturity (Kung and Stanley, 1982). Sugarcane silage is significantly lower in total digestible nutrients than fresh chopped sugarcane or corn silage due to large losses of available sugars with seepage and conversion to ethanol in the ensiling process (Kung and Stanley, 1982). In addition to losses in the nutritive value of sugarcane when ensiled, silage feeding leads to extra expenses which are unnecessary since cane maintains good quality as a standing crop.

Composition of Sugarcane

Standing mature cane consists of slightly more than 70% moisture. The dry matter fraction is comprised of sucrose and other sugars, the cell walls (fiber) and small amounts of minerals and nitrogen (Barnes, 1964). Sugarcane is characterized by having highly soluble sugars that are readily fermented in the rumen, and cell wall components that are very insoluble and poorly digested by the rumen microbes. The carbohydrate component does not contain starch and the level of total nitrogen is extremely low (Preston, 1982). Pate (1979) reported that as sugarcane matured, dry matter percentage increased in a curvilinear manner from approximately 9 to 29%, while percent crude protein and ash dropped rapidly, especially during the early stages of growth. Fibrous components also dropped, probably due to an increase in sucrose content of the mature cane. The average crude protein content of 66 varieties of sugarcane was 2.32% (± 0.42); (Pate and Coleman, 1975) with a range of 1.06 to 3.06%. The low nitrogen levels observed emphasizes the generally accepted view that nitrogen is the major constraint to animal production on cane based diets, making nitrogen supplementation imperative to ensure good animal performance.

Intake and Digestibility of Sugarcane

An important factor in the utilization of a product for animal feeding is its voluntary intake by the animals to which it is fed. Intake depends on the acceptability of the feed and the rate of passage in the digestive tract, which is sometimes related to the rate of digestion. Voluntary intake accounts for about 70% of the differences observed in digestible energy intake of forages by cattle

while digestibility accounts for 30% of the variation in digestible energy intake (Donefer, 1970; Heaney, 1970).

In spite of sugarcane's high levels of readily fermentable sugars, its voluntary intake by cattle is generally low (Preston, 1977; Pate, 1981). Low intake has been attributed to poor fiber digestibility (Valdez and Leng, 1976). The consumption of high levels of sugars, as in sugarcane, is believed to decrease the growth of cellulolytic bacteria and inhibit cellulase activity, thereby decreasing fiber digestibility (Hungate, 1966). Particle size of sugarcane was reported to be insignificant as a factor affecting intake and digestibility of sugarcane diets (Montpellier and Preston, 1977). Caielli (1972) also found no differences in intake or daily gain between diets containing either chopped or finely ground sugarcane. However, feeding of derinded sugarcane stalk resulted in significant increases in dry matter digestibility over cane tops, rind and whole plant material (Montpellier and Preston, 1977), exemplifying the negative effects of fiber on dry matter digestibility. Creek et al. (1976) reported that feed intake increased as the particle size of sugarcane decreased which is in agreement with the view that grinding forages increases rate of passage and feed intake (Rodrique and Allen, 1960; Johnson et al., 1964; Buchman and Hemken, 1964; Moore and Mott, 1973). Intake of cane was also considered to be limited by the low level of nitrogen, but Ferreiro and Preston (1977) showed that there was no response in intake to different nitrogen sources and it was concluded that some other nutrient might have limited intake.

Rumen Metabolism with Sugarcane Diets

All feedstuffs fed to ruminants undergo microbial fermentation in the rumen. Ideally, when feeding ruminants one should think in terms of feeding rumen microorganisms because they dictate to a large extent the host's productive performance through their influence on the type and amount of fermentation end products. Fermentation was considered by Hungate (1966) as being a limiting process in animal production, especially if high quality feeds are fed. However, the ruminant's ability to convert the β -linked polysaccharides into useful end products and to fix NPN into microbial protein, and its subsequent digestion in the lower digestive tract, enhances the opportunity of the ruminant to survive and provide for human needs without grains or similar high quality feeds. Non-protein nitrogen supplementation to sugarcane based diets appears to provide an ideal situation for the utilization of both sugarcane and NPN in animal production systems in the tropics.

Ferreiro et al. (1977) reported that the rumen fermentation pattern of cattle fed sugarcane was not affected by the nature of the carbohydrate supplement or the source of nitrogen. A wide range of energy/protein supplements (maize grain, rice polishings, cottonseed meal) had no effect on the relative proportions of the rumen volatile fatty acids (VFAs); (Minor et al., 1977). An exhaustive study by Valdez et al. (1977) using sugarcane diets showed that the pattern of VFAs, concentration of ammonia and protozoal biomass did not change after rice polishings were fed, even though this supplement has been shown to increase animal performance (Preston et al., 1976; Lopez et al., 1977b). Monensin, which has been reported to alter VFAs'

proportions in cattle fed high concentrate diets (Richardson et al., 1976) did not affect the VFAs' pattern when fed to cattle consuming sugarcane (Lopez et al., 1977a).

Valdez et al. (1977) observed a definite pattern of substrate utilization on sugarcane based diets. Shortly after feeding, acetic acid decreased while propionic acid increased. These changes were attributed to bacterial fermentation of soluble sugars since the large holotrich protozoa (which comprised 80% of all protozoa biomass) are believed to produce acetic, butyric and lactic acid (Hungate, 1966). It was suggested that shortly after feeding, the protozoa stored starch from soluble sugars which resulted in an observed increase in acetic acid before the next feeding. This increase in acetic acid was thought to come from the fermentation of starch stored by protozoa with secondary fermentation of lactate by bacteria to a mixture of VFAs. As the protozoal fermentation of stored starch was depleted, cellulose digestion would increase as reflected by the observed higher acetate proportions with time after feeding, implying a succession of microbial communities in the rumen.

Since little change occurs in the rumen fermentation of cattle fed sugarcane with different supplements, the effects of supplemental rice polishings or any other concentrate on animal performance would possibly be mediated directly through the provision of essential nutrients for absorption.

Animal Production on Sugarcane Diets

Good growth by cattle fed sugarcane/urea diets supplemented with rice polishings has been reported (Alvarez and Preston, 1976; Preston et al., 1976; Ferreiro and Preston, 1976a). However, responses to traditional protein supplements and concentrates have been variable

and usually less per unit of added protein than when rice polishings were used (Silvestre et al., 1977a; 1977b; Lopez et al., 1977b). Lack of good animal performance has been attributed to sugarcane's failure to supply metabolizable protein or amino acids and glucose precursors at the metabolic level (Leng and Preston, 1976).

Siebert et al. (1976) evaluated sugarcane diets supplemented with either meat meal, leucaena (Leucaena leucocephala), or urea and sodium sulphate. During the first month of the study, only steers fed sugarcane with meat meal showed a positive weight gain (.59 kg/day). All steers gained weight during the following month, although steers receiving urea and sodium sulphate gained at a lower rate (.43 kg/day) than those receiving either meat meal or leucaena (.61 kg/day). In a 93 day feeding trial, Fairhurst (1981) found that steers gained .91, .73 and .62 kg/head/day on sugarcane, cottonseed meal, corn meal and urea diets in which urea provided 0, 25, or 50% of the diet nitrogen, respectively. Lower performance by steers fed the highest level of urea was essentially attributed to delayed adaptation of the animals to urea. During the final 65 days of the experiment, the level of urea in the diet had less affect on rate of gain (.98, .90, and .85 kg/day for the 0, 25, and 50% urea nitrogen levels, respectively). The development of a specific rumen microbial population capable of using NPN efficiently has been reported (Smith et al., 1960; Oltjen et al., 1969; Virtanen as cited by Goodrich et al., 1972). If there is little change in the rumen fermentation of cattle fed sugarcane diets, as discussed in the preceding section, feeding NPN with a suitable source of carbohydrate (corn meal) that has an intermediate rate of degradation, and hence likely to bypass, would probably

increase microbial protein synthesis and bypass nutrients of animals fed sugarcane. Therefore, production by such animals would be expected to increase since VFAs, protein and energy (glucose) would not be limiting production.

Ferreiro et al. (1977) compared rice polishings, maize grain, fish meal and soybean meal, and maize oil or their combinations to provide different combinations of essential amino acids, starch and unsaturated lipids as supplements to sugarcane diets. Cattle had free access to molasses containing 10% urea, 1% ammonium sulphate and minerals in addition to sugarcane. Supplementing the diet with 500 g daily of corn did not increase the growth of steers over those fed the unsupplemented diet. Growth was significantly improved by feeding 500 g/day of fish meal/soybean meal mixture, and there was a further increase in liveweight gain when either 30 ml/day of maize oil or 500 g/day ground maize was fed with fish meal/soybean meal (Ferreiro et al., 1977). Increasing fish meal/soybean meal to 750 g/day increased rate of gain by an additional 100 g/day, and this performance was similar to that obtained with 1000 g of rice polishings. Since corn starch is known to be incompletely fermented in the rumen, and likely to bypass the rumen undigested, the lack of response to 500 g/day of corn alone implied that glucose precursors may not always improve animal performance when added to sugarcane/urea diets. The urea and protein nitrogen from corn was probably not enough to supply the amino acids required by the animal. This was depicted further by the greater animal performance when 500 g/day ground corn and 500 g/day fish meal/soybean meal were fed together, and the superior performance

when rice polishings was fed compared with mixed protein from fish meal and soybean meal, even though the amount of protein provided by the rice polishings was less than half that provided by the mixed protein sources. The superiority of rice polishings over other starches suggested differences in the rate at which various sources of starch are degraded in the rumen and their potential bypass characteristics. Therefore, the concept that sugarcane/urea based diets are deficient in bypass nutrients is tenable.

Molasses

Terminology

The term molasses can be confusing if not defined because there are many types of molasses which include sugarcane, beet, citrus and wood molasses. Only molasses from sugarcane will be dealt with here. There are also different kinds of molasses resulting from various stages of sugar extraction starting with raw sugarcane. The cane molasses usually fed to cattle is blackstrap or final molasses. Blackstrap molasses is the by-product of raw cane sugar production from which the maximum sugar has been extracted and normally the term molasses, if used without specification, refers to blackstrap molasses. Blackstrap molasses is often diluted to a standard Brix of 79.5° by adding water to adjust the density to the prescribed Brix (Crochet, 1963).

Molasses Uses

Blackstrap molasses has been fed to cattle mainly as a feed additive to improve the palatability and pelleting characteristics of feeds. In dry feeds, molasses does not only increase palatability, reduce dustiness or serve as a binder, but can actually be used to

replace other more expensive carbohydrates. Molasses has also been used in silage making from grasses to improve the fermentation characteristics by supplying readily fermentable sugars. Molasses has been widely used as a carrier for urea in liquid supplements for ruminants. Recently molasses has been used at high levels in cattle rations to substitute for grains in areas where there are surpluses of molasses and scarcities of grain. It is the abundance and cheapness of molasses in countries where sugarcane industries exist that make molasses feeding to animals attractive.

Nutritive Value of Molasses

Although a number of studies have shown improvements in the rate of gain and/or dry matter utilization by cattle supplemented with molasses up to 10% of the dry matter of concentrate diets (Lofgreen and Otagaki, 1960a; Lishman, 1967; Brown et al., 1967; Cooper et al., 1978), the use of higher levels of molasses has been reported to decrease rate of gain (O'Mary et al., 1959; Lofgreen and Otagaki, 1960a; Campbell et al., 1970; Heinemann and Hanks, 1977).

Lofgreen and Otagaki (1960a) reported that the net energy value of molasses decreased as the level of molasses increased from 20 to 25 and 40% of the diet. They also reported that the net energy of molasses for lactation when fed at levels of 10 and 30% of the total ration was 68.1 and 23.1 Mcal per 100 lb, respectively, compared with 54.2 Mcal for the basal ration. Such energy losses could not be accounted for by fecal energy losses (Lofgreen and Otagaki, 1960a), but changes in VFAs' proportions and their efficiency of utilization were implied.

In general, molasses has approximately 80% dry matter, 4.5% CP, 12% ash, 4.0% potassium, 35% sucrose, 7.0% glucose, 9.0% fructose and 4.0% other carbohydrates (Meade and Chen, 1977; Paturau, 1969). The preceding average composition of molasses indicates that molasses is low in CP and roughage but has high levels of readily fermentable carbohydrates and ash, with potassium comprising about 33% of the ash content. The presence of high levels of potassium might increase the requirement for sodium in high molasses diets whereas high levels of sugars make NPN supplementation a sensible possibility. Overall, Scott (1953) concluded that the average nutritive value of molasses was about 85% of maize grain, and that molasses would only be 75% as valuable as maize grain under unfavorable conditions.

Intake of Molasses

Molasses is usually fed at up to 10% of the diet to improve palatability and diet intake. More recently, higher levels of molasses have been used to replace costly carbohydrate ingredients in cattle rations. Preston and Willis (1969) reported that molasses palatability and intake varied with the type of feed offered with molasses. Zebu bulls with free access to molasses/urea in addition to either ground sorghum grain or elephant grass (Pennisetum purpureum) forage consumed only 11% of the total diet metabolizable energy (ME) as molasses in preference to grain, as compared to 58% of the diet ME as molasses when freshly cut forage was offered. Martin et al. (1968) reported that restricting forage intake to 1.5% of the animals' liveweight per day increased ME consumption of molasses to 72% of the diet as opposed to 33% when forage was fed ad libitum. Pate (1973; 1974) also reported low consumption of molasses by steers grazing

pastures grown on organic soils. In two out of three studies conducted, daily molasses intake was below 0.5% of body weight.

Adding 3% urea to molasses increased molasses intake by 28% (Preston et al., 1967) while adding urea to molasses at 2% increased voluntary intake of molasses by grazing cattle by 12 to 15% (Porres, 1971) over those which were not fed urea. Pate (1974) also reported an increase in molasses consumption when cottonseed meal was incorporated into molasses fed to grazing cattle.

Based on the above reports, it appears that molasses is not necessarily palatable over all feeding conditions. Its consumption seems to vary with nitrogen supplementation, source of nitrogen and probably the quality of the remainder of the ration.

Effects of Molasses on Rumen Metabolism

There is general agreement in the literature that sucrose and other soluble sugars from molasses (Geerken and Sutherland, 1969; Kowalczyk et al., 1969; 1970; Ramirez and Kowalczyk, 1971) or sugarcane (Elliot et al., 1978) are almost completely fermented in the rumen. It is also reported that no glucose is absorbed from the rumen (Smith et al., 1979). The implication is that animals fed solely on sugarcane/molasses diets supplemented with NPN would have to rely heavily on gluconeogenesis for their supply of glucose, and that improvements in animal production would be achieved only if sugarcane/molasses based diets supply adequate amounts of glucose precursors such as propionic acid.

Although molar proportions of propionic acid in the rumen contents of cattle fed cane diets have been reported to be within the

normal range of 20 to 25% (Leng and Preston, 1976), several studies have shown that feeding diets containing high levels of molasses produce different VFA patterns. Elias et al. (1968) reported unusual patterns of rumen fermentation when diluted molasses (15% soluble solids) was fed. The pH was 6.8 and the VFAs' concentration was 90 to 100 Mequiv/l. The pH was much higher while the concentration of VFAs was much lower than those reported (Elias et al., 1968) for similar animals fed equivalent amounts of readily available carbohydrates in the form of starch (i.e., 6.0 and 125 to 129 for pH and VFAs, respectively). A subsequent study (Elias and Preston, 1969) confirmed the relatively high values of pH (6.6 to 6.8) when concentrated molasses (75% soluble solids) was fed, but total VFAs concentration was higher (124 Mequiv/l). Marty and Preston (1970) reported that the molar proportions of acetic, propionic, butyric and valeric acids were 31, 19, 41 and 9%, respectively, in the rumen fluid of fattening bulls fed a diet containing 77% molasses. The levels of butyric acid and valeric acid were also very high for either dairy cows (29 and 10%) or weaned calves (37 and 14%, respectively). The high proportions of a n-butyric acid and n-valeric acid appeared to rise at the expense of acetic acid because propionate levels were within the normal range. However, Rowe et al. (1979) reported that VFAs proportions of cattle fed high levels of sugarcane and molasses were characterized by having low propionate concentrations, a pattern similar to that seen for ketotic dairy cows (Radloff and Schultz, 1967). Silvestre et al. (1977b) and Reyes (1974) also reported that there were high molar percentages of butyric acid, but low propionic acid levels in the rumen fluid of cattle fed high levels of molasses in a forage based

diet. In general, it appears that feeding high levels of molasses or sucrose to cattle whose diets are based on forage, substantially increases the level of n-butyrate and/or n-valeric acid at the expense of acetic acid (Pierson and Otterby, 1971; Rumsey et al., 1971; Karalazos and Swan, 1975; Seibert, 1978). If molasses is used to replace concentrates in finishing diets, then the increase observed in butyric acid is at the expense of propionic acid (Olbrich and Wayman, 1972). When molasses levels were lower than 15% of the total diet, there was very little effect of molasses concentration on VFAs pattern (Martin and Wing, 1966; Hatch and Beeson, 1972), although the molar percentage of isovaleric acid was found to be low in the rumen contents of steers fed diets containing molasses (Martin and Wing, 1966).

Utilization of Carbohydrates by Ruminants

The major portion of a ruminant's diet is carbohydrates, and these can be categorized into two main types, namely, structural carbohydrates (comprised of cellulose and hemicellulose) and nonstructural carbohydrates, also known as readily available carbohydrates. The readily available carbohydrates can possibly be further categorized as very soluble (mostly sugars) and sparingly soluble (starches). The structural carbohydrate or fibers are the main type contained in forages and glucose is the principal intermediate breakdown product of both starch and cellulose. Pentoses are the intermediate breakdown products of hemicellulose. Pentoses are converted to hexoses prior to further catabolism so that the majority of dietary carbohydrate metabolism in the rumen is mediated via the hexoses which are further fermented to yield pyruvate, lactate

and later carbon dioxide, methane, VFAs and adenosine triphosphate (ATP). Methane production represents a loss of feed energy, while VFAs can be absorbed by the animal to meet its nutritional requirements. The generated ATP can be used for de novo synthesis and maintenance of microbial cells.

Stoichiometric estimates indicate that only 4 to 5 ATPs are generated per hexose molecule fermented in the rumen and this represents about 10 to 12% of its potential aerobic yield (Hungate, 1966). The role of carbohydrates in microbial growth is to provide ATP and carbon skeletons (Helmer and Bartley, 1971), which are accompanied by the production of VFAs as end products. Since ruminants rely heavily on VFAs and microbial protein as sources of energy and amino acids, respectively, the significance of different types of carbohydrates would depend on their ability to produce VFAs while supporting adequate microbial growth.

There are considerable variations in the rate and extent to which different carbohydrates are fermented. The highly soluble carbohydrates, like sucrose, are generally the most rapidly fermented, followed by starch, and then the insoluble carbohydrates like cellulose (Helmer and Bartley, 1971). Variations in the rate of fermentation also occur within each type of carbohydrate. Sutton (1968) reported that among the simple sugars, glucose, fructose and sucrose were the most rapidly fermented while galactose, arabinose and xylose were fermented at approximately half the rate of glucose fermentation. Such variations could be ascribed to the number of bacterial species capable of fermenting a given source or type of carbohydrate. Hungate (1966) reported that of the 22 bacterial species in the rumen, 18

could ferment glucose, 14 were able to ferment fructose, and sucrose could be fermented by 15 bacterial species. It was also reported (Hungate, 1966) that some bacteria could ferment either one or two of the aforementioned sugars but not all three sugars. Therefore, the rate at which each carbohydrate is fermented would not only depend on the diet composition but also upon the prevailing microbial population in the rumen.

Simple sugars are completely fermented in the rumen, and 97 to 99% of starch is digested in the entire digestive tract (Karr et al., 1965; Singleton, 1972; Waldo, 1973; Russell et al., 1981). Russell et al. (1981) found that about 70% of the starch presented to the reticulorumen was digested when ground shelled corn comprised 38 or 56% of the diets dry matter. Thus, about 30% of the starch would be able to bypass rumen fermentation. Karr et al. (1965) and Armstrong and Smithard (1979) reported that the amount of starch escaping ruminal fermentation increased as corn starch consumption increased, and it has also been observed that total tract starch digestibility decreased as concentrate intake by lactating dairy cows (Wheeler et al., 1975) and steers (Galyean et al., 1979) increased above maintenance. However, the significance of decreased overall starch digestibility might be offset by the increase in energy yields (11 to 30%) obtained when starch is digested postruminally as opposed to fermentation in the rumen (Owen and Isaacson, 1977). Growth responses by sheep to postruminal glucose and protein infusions were reported by Leng et al. (1978), reflecting that bypass nutrients might be essential for maximum animal performance.

Of the types of carbohydrates, structural carbohydrates are the least rapidly fermented, and the observed variations in the digestibility of forages is generally attributed to the cell wall constituents which vary with forage species and stage of maturity (Van Soest, 1965a; 1965b). The low digestibility of structural carbohydrates is complicated by their association with lignin. Lignin has been shown to vary inversely with forage quality (Van Soest, 1965a; 1965b; 1967) and that lignification of the structural carbohydrates increases with forage maturity (Minson et al., 1960). Low animal production when forages are fed, as compared to concentrate based diets, has been partly ascribed to reduced fiber digestibility, which would reduce feed intake (Conrad, 1966; Baile, 1968) and, hence, reduced production of VFAs and microbial protein synthesis (Hogan et al., 1969).

Other factors that would reduce fiber digestibility and forage intake include low nitrogen levels (<7% CP) in mature forages (Milford and Minson, 1965; Minson, 1967), and extremely low level of soluble carbohydrates such as fructosans (Blaser, 1964), and other soluble cell contents. Supplementation of nitrogen and/or readily available carbohydrate sources such as molasses, sucrose and starch to diets high in fiber to improve their utilization has resulted in variable responses depending upon the quantity and source of the carbohydrate used as a supplement.

Effect of Readily Available Carbohydrates on the Digestibility of Fiber

There is a general agreement in the literature that fiber digestibility declines when high levels of readily available carbohydrates are fed with roughages (Mitchell et al., 1940; Hamilton, 1942; Burroughs et al., 1950; Fontenot et al., 1955; Hungate, 1966; Chappel and

Fontenot, 1968; Martin et al., 1981). It is also widely recognized that increases in the fiber content of diets, brought about by increasing either the proportion of roughage in mixed rations or the fiber content of all-forage diets, cause a decrease in the digestibility of most components of the diet except the fiber itself, the digestibility of which usually increases with increasing proportions of roughage in mixed rations (Broster et al., 1978). Chappel and Fontenot (1968), using purified diets, reported that levels of readily available carbohydrates of 32% or below did not significantly alter cellulose digestibility, and concluded that cellulose digestibility in purified diets would decrease only when the approximate level of nitrogen free extract exceeded about 30%.

In spite of the general depression in crude fiber digestibility when high levels of readily available carbohydrates are fed, small amounts of such carbohydrates have been found to be important in initiating an active population of rumen microflora and, hence, speed up fiber digestion. Arias et al. (1951) reported that adding 1.0 g of sucrose or starch, 1.0 to 2.0 g of dextrose to 9.0 g of cellulose in vitro, increased cellulose digestion, but not with the addition of 2.0 g or more of sucrose or starch, or 3.0 g of dextrose. Similar reports have been reported by other researchers (Pearson and Smith, 1943a; Belasco, 1956; Richardson et al., 1961).

Seibert (1978) compared the effects of similar levels of sucrose, starch and cellulose on the digestibility of fiber in the total ration containing bagasse. The apparent digestibility coefficients for neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose and lignin differed among the three carbohydrate sources. The estimated NDF digestibility for bagasse was highest in the cellulose diet and

lowest in the sucrose diet, indicating that the more rapidly a carbohydrate supplement is fermented, the lower the digestibility of fiber in that diet. Head (1953) found that the addition of protein to diets containing either potato or maize starch did not stop the depressive action of readily available carbohydrate on cellulose digestibility, and it was concluded that microbial growth did not depend on supplemental nitrogen when its level approached 1.0%.

Apart from the effects of readily available carbohydrates on fiber digestibility, the level of feed intake has been reported to decrease fiber digestibility. Zinn and Owen (1983), using diets that contained 80% concentrates, found that as feed intake by steers increased, organic matter and ADF digestibility decreased. At the highest level of intake (2.1% of body weight), no ADF digestion from the rumen occurred. It was thus concluded that level of feed intake altered fiber digestibility and level of bypass nutrients, and suggested that a source of degradable nitrogen in the rumen was required to promote microbial growth at high levels of feed intake.

Effect of Urea on Fiber Digestion

Early studies by Gallup et al. (1952) indicated that the addition of urea to basal diets comprised of 84, 49 and 28% roughage as cottonseed hulls, and containing 7.20, 6.81 and 6.44% CP, respectively, significantly increased the digestibility of organic matter by 6-8% and nearly doubled the amount of crude fiber digested in the low roughage diet. It was also observed that the repressive action of readily available carbohydrates was partially overcome by urea supplementation, which is slightly at variance with the conclusion by Head

(1953). The high roughage diets had a higher crude fiber digestibility than the low roughage diets. Similar results were reported by Gallup et al. (1954) who found that urea and soybean meal had similar effects on increasing organic matter digestibility, although urea gave lower fiber digestibility than soybean meal at equal levels of crude protein.

Colovos et al. (1965), using late-cut hay and concentrate mixtures containing 5 or 10% fiber, reported non-significant effects of increasing urea in the concentrate mixture on the digestibility of fiber. Each concentrate mixture was tested with 0, 10, 20 and 40 lb of urea per ton, or the equivalent of 0, 8.75, 17.5 and 35% CP of the concentrate mixture. However, fiber digestibility was lower in the 10% fiber concentrate mixture than in that containing 5% fiber. Colovos et al. (1967a; b) also reported a lower fiber digestibility in the 8% fiber concentrate mixture than in the concentrate mixture containing 5% fiber. The diets contained 0 to 2.5% urea on dry matter basis. The low fiber digestibility of the high fiber diets was attributed to the high dry matter intake by animals fed the higher fiber diets. Fairhurst (1981), using sugarcane based diets with increasing levels of urea in the dry matter, (concluded that urea had no effect on the digestibility of nutrients in high sugarcane diets.)

Although urea supplementation appears to increase the digestibility of crude fiber or give similar results to natural proteins when fed with concentrates, its effects seem to be associated with increasing the overall CP content of the diet (Knott et al., 1972). Organic matter digestibility was shown to increase as urea was

used to raise the CP content of the diet from about 6.0 to 11.0% (Gallup et al., 1952), and that similar results were obtained with urea and soybean oil meal in the presence of concentrates when fed to give the same level of CP (Gallup et al., 1954). Therefore, the influence of urea on organic matter or fiber digestibility would be expected to be similar to that of other degradable sources of nitrogen like soybean meal, casein or meat meal when fed to provide similar levels of nitrogen in concentrate feeds.

Urea Feeding to Ruminants

When urea is fed, microorganisms in the reticulo-rumen generate urease that decomposes urea to NH_3 . Urease activity in the rumen was reported by Pearson and Smith (1943b) to be sufficient to convert rapidly to NH_3 all the urea ever likely to be included in the diet as a partial substitute for protein. The rate at which NH_3 is produced may exceed the rate of protein synthesis by the microorganisms (Bloomfield et al., 1960; Chalupa et al., 1964), particularly when large amounts of urea or readily degradable proteins are fed. For example, Bloomfield et al. (1960) reported that urea was hydrolyzed at the rate of approximately four times faster than that at which the generated NH_3 was utilized. Ammonia is an essential nutrient for the growth of most of the microorganisms (Bryant and Robinson, 1962; 1963). Rumen NH_3 is either synthesized into microbial protein or absorbed through the rumen wall (McDonald, 1948) and excreted as urea in the urine (Lewis, 1957) or returned to the rumen via saliva (Bailey and Balch, 1961; Somers, 1961a; 1961b; 1961c; 1961d) and across the rumen wall (Juhasz, 1965; Packett and

Groves, 1965; Cocimano and Leng, 1967; Houpt and Houpt, 1968). As reviewed by Waldo (1968), the transfer of urea across the rumen wall is more important than recycling via saliva.

There is a critical level of NH_3 in rumen fluid ranging from 20-50 mg N/L below which microbial growth or efficiency may be reduced (Satter and Slyter, 1972; 1974). Maintenance of ruminal NH_3 -N in excess of 5 mg/100 ml rumen fluid had no effect on microbial protein production (Satter and Roffler, 1977). Since the only known beneficial effect of urea feeding is the production of NH_3 in the rumen, the most efficient use of urea would be limited to conditions where NH_3 concentration would be below the optimum level for microbial growth. Such optimal conditions are influenced, among other factors, by the level of dietary protein intake, and the supply and type of carbohydrates as related to microbial growth, rate of passage and, hence, NH_3 utilization.

Effect of Level of Dietary Protein Intake on Urea or NPN Utilization

The influence of protein on NPN or urea utilization depends on the extent to which protein is degraded to NH_3 . A highly hydrolyzable protein would result in the production of incremental amounts of NH_3 in the rumen that would compete with NPN NH_3 . A diet that is already providing adequate levels of NH_3 in the rumen for microbial growth would not benefit from NPN supplementation. Wegner et al. (1941) observed that as the concentration of casein (a highly soluble protein) was increased from 2.5 to 5 g/100 ml of an in vitro medium, the rate of conversion of the added NH_3 to the protein was negligible. This work was followed by in vivo studies in which a

cow was fed corn silage, timothy hay and a basal concentrate mixture consisting of ground corn and oats in the ratio of 1:1. Nitrogen utilization was determined by measuring total NPN, concentration of protein and $\text{NH}_3\text{-N}$ in the rumen ingesta. Urea utilization decreased as the crude protein content of the concentrate, provided by linseed meal, was increased above 18%. Additional urea to the basal concentrate (11.3% CP) to give 23% CP increased urea utilization. Gallup et al. (1952) reported that the addition of urea to a basal diet containing 7.8% CP and comprised of either cottonseed meal, soybean oil meal or corn gluten meal to give diets of 10.6% CP resulted in similar nitrogen retention by lambs. The same study showed that nitrogen retention from the three rations without urea supplementation was similar, thereby indicating that at low levels of protein intake N is utilized with similar efficiency regardless of source of N. Polan et al. (1970) stated that increasing urea-N in the diet decreases N-retention but increases apparent N digestibility so long as the diet contains less than 14% CP.

The anaerobic nature and other characteristics of the ruminal fermentation put a ceiling to the potential nutrient yield for the host from this fermentation. For example, the presence of $\text{NH}_3\text{-N}$ in excess of 5 mg/100 ml of rumen fluid had no effect on protein yield of the fermenter effluent (Satter and Roffler, 1977). Mean ruminal NH_3 concentration was found to be positively related to percent CP in the ration dry matter, but as dietary CP increased above 13%, ruminal ammonia increased rapidly and was in excess of 5 mg $\text{NH}_3\text{-N}$ /100 ml rumen fluid (Satter and Roffler, 1977). Therefore, when a diet

exceeds 13% CP, the addition of NPN or urea would be wasteful. The work of Orskov et al. (1974) indicated that the level of supplementary protein above which urea supplementation would cease to be beneficial would vary with the susceptibility of that particular protein to degradation. They stated that as the level of intake of fish meal was increased, the amount of non-microbial protein reaching the abomasum was increased, whereas feeding a high level of fish meal and urea gave no response to urea. Since urea or NPN does not spare preformed protein in the rumen (Orskov et al., 1974), maximum benefits from feeding both urea and protein would be expected only if the two sources of N are fed to provide the required level of CP.

Effect of Source of Carbohydrate on Urea Utilization

Energy availability under anaerobic conditions has been considered to be the most limiting factor for microbial growth (Gunsalus and Shuster, 1961). Bauchop and Elsdon (1960) reported that the amount of growth of microorganisms was directly proportional to the amount of ATP that could be obtained from the degradation of the energy source, and the relationship between ATP and cell growth was defined as grams (g) of organisms (dry weight basis) per mole of ATP. In vitro isotope incorporation studies with rumen contents (Buchultz and Bergen, 1973), energy balance calculations from ruminal fermentation (Baldwin, 1970), and ingesta passage studies with sheep using NPN-containing diets or microbial cell markers (Hume et al., 1970; Hogan and Weston, 1971; Lindsay and Hogan, 1972) showed that microbial protein synthesis was from 15 to 22 g/100 g of organic matter fermented. Hagemeister et al. (1980) using data from 75 trials found that 22.1 g of microbial protein was synthesized for every 100 g

of fermentable organic matter. Hagemeister et al. (1980) also reported that a high proportion of roughage in the ration would yield only 15 to 20 g of microbial protein per 100 g of organic matter apparently digested (OMAD) in the rumen, whereas rations with extremely high levels of concentrates would result in about 14 to 18 g of microbial protein per 100 g OMAD. Similar results were reported by Chamberlain and Thomas (1979) and Mathers and Miller (1977; 1981). Low microbial protein yields with diets high in concentrates was attributed to low rumen pH caused by concentrates.

In vitro studies conducted by Belasco (1956) showed that small amounts of starch, xylan and pectin increased urea utilization by 33, 16 and 18%, respectively. It was also shown that as starch or cellulose increased from 1.0 to 18.0 g, there were corresponding increases in urea utilization and reductions in NH_3 concentration in the medium. Starch was generally shown to give better urea utilization than cellulose at comparable levels and that 18 g of a 50:50 mixture of starch and cellulose resulted in better urea utilization than that observed with 18 g of either starch or cellulose. Urea utilization, cellulose digestion, and VFAs production were maximized when the ratio of cellulose to starch ranged from 0.5 to 2.0 in a medium that had a constant total carbohydrate concentration of 1.0%. Similar results were reported by Pearson and Smith (1943b) and Arias et al. (1951). Drori and Loosli (1961) found that the nitrogen retention by sheep and biological values obtained with diets containing either sucrose or starch with urea were not significantly different, although a diet of soybean meal and corn was

superior to the two urea diets. Tagari et al. (1964), using high protein diets, reported that the replacement of roughage carbohydrates by starch induced a rise in NH_3 liberation and hence an impairment in protein utilization, although the same authors found that the concentration of amino acids in the rumen liquor was greatly increased by a starch-containing ration. Nitrogen retention decreased even though protein digestibility increased, indicating that the breakdown of protein in the rumen may reduce its quality or decrease the amount of protein reaching the lower digestive tract while increasing urinary nitrogen losses. Even though starch appears to be better than cellulose in capturing rumen NH_3 , low nitrogen retention with such diets when fed with NPN would imply that the rate at which NH_3 is removed from the rumen exceeds that of microbial cell synthesis.

Al Attar et al. (1976) reported that when sucrose comprised 50% of energy intake, utilization of available energy for microbial growth was reduced by more than 50%. Ramirez and Kowalczyk (1971) found that the synthesis of microbial protein in bulls fed a protein-free diet based on molasses and urea was about 15.7 g/100 g of readily fermentable carbohydrates, and similar results were reported by Kowalczyk et al. (1970). Bell et al. (1953) found significantly lower nitrogen retention by steers fed a prairie hay diet supplemented with 40% molasses-urea than steers supplemented with corn and urea. The preceding studies agree with in vitro studies that showed sugars, and especially sucrose, to be less effective than starch in promoting nitrogen utilization from urea (Pearson and Smith, 1943b; Belasco, 1956).

Although there are differences in the utilization of NPN or NH_3 caused by various sources of carbohydrates, the reasons for the differences are not well understood. Nevertheless, Stouthamer and Bettenhausen (1973) and Isaacson et al. (1975) reported that microbial protein synthesis or NH_3 utilization depended upon the microorganisms' specific growth rates and their maintenance requirements. Thus, slow growing microorganisms had higher maintenance requirements than those growing at fast rates. Rations with large amounts of fiber are fermented at slow rates, leading to slow production of ATP for microbial growth, but increasing microbial needs for ATP for maintenance. Rations which are extremely high in readily fermentable organic matter would result in low pH, narrowed acetic/propionic acid ratios and lactic acid formation, conditions that would induce acidosis and decrease microbial growth (Van Soest and Demeyer, 1977; Russell and Baldwin, 1979a; 1979b).

Rumen Volatile Fatty Acids (VFAs) and their Utilization

Although VFAs were known to be present in the rumen as early as 1831 (Tiedmann and Gmelin, as quoted by Hungate, 1966), it was Phillipson and McAnally (1942) who clearly showed that carbohydrates were fermented to VFAs and that such similar substrates as mono- and di-saccharides were fermented at very different rates. Similar results were reported by other workers (Quin, 1943; Satter et al., 1964; Thomas, 1960; Sutton, 1968; 1969). Sutton (1968) compared the ability of glucose, fructose, galactose, xylose, arabinose, and sucrose to produce VFAs under in vivo and in vitro conditions when hay was given as a basal diet. In vivo studies showed that changes in proportions of VFAs in the rumen indicated marked differences among

the carbohydrates in the proportions of VFAs produced. After incubating the carbohydrates for two hours, it was found that between 97 and 100% of the sucrose, glucose and fructose were fermented, but only 42-56% of the other carbohydrates. Acetic acid was the predominant acid produced, especially with galactose and pentoses. Propionic acid constituted less than 20% of the VFAs produced from galactose but about 30% from the other carbohydrates. n-Butyric acid comprised of about 20% of the VFAs from the hexoses and sucrose but only 10% from pentoses. Relatively high amounts of lactic acid were produced from glucose and fructose only. In a subsequent study, Sutton (1969) used the same carbohydrates as in the preceding study but used cows that were fed large quantities of flaked maize instead of hay. Of the VFAs produced from galactose and pentoses, acetic acid constituted 40%, propionic acid 45-55% and n-butyric acid 1-7%, while about 40% acetic acid, 20-40% propionic acid, 14-22% n-butyric acid and 12% n-valeric acid were produced from fructose and sucrose; and glucose had intermediate effects. Sutton (1968; 1969), therefore, showed that different simple carbohydrates were fermented at different rates and that products of fermentation varied according to the nature of the basal diet.

The influence of source and quantity of carbohydrates on the production of VFAs was reported by Belasco (1956). Total VFAs production increased with additional amounts of either starch or cellulose to an in vitro medium of molasses ash, cellulose, corn starch, xylan, pectin, dextrose, urea and mineral salts. The addition of starch produced more VFAs than comparable amounts of cellulose, and

a combination of equal parts of starch and cellulose produced more VFAs than either starch or cellulose alone. Increasing the quantity of starch to a medium of cellulose and urea increased the molar proportion of butyric and valeric acid, while decreasing acetic acid and slightly reducing propionic acid. Doubling the quantity of cellulose increased the percentage of propionic acid and decreased acetic acid. Owen et al. (1967) and Kellog and Owen (1969) reported that the addition of either 6 or 9% of sucrose in the total dry matter of dairy rations reduced the efficiency of energy utilization for milk production while increasing the molar percentage of butyric acid in the rumen without consistent trends in the percentage of acetic acid or propionic acid. Bath and Rook (1963) found that the addition of corn or sucrose increased the proportion of propionic acid while only sucrose increased the proportion of butyric acid.

Seibert (1978) compared the effects of raw sugar, corn meal and flaked soybean hulls as sources of either sucrose, starch or cellulose, respectively, on rumen VFAs concentration. The basal diet was composed of raw bagasse, cottonseed meal, molasses, urea and minerals. It was found that the proportions of VFAs produced were dependent on the carbohydrate source in the diet. Sucrose produced more butyric acid but less acetic acid than starch or cellulose diets. Sucrose also produced the highest concentration of valeric acid. The cellulose diet produced more acetic acid than the sucrose diet and more isovaleric acid than either the starch or sucrose diet. However, there were no significant differences in the total amount of VFAs produced among the diets.

A main cause for the changes in rumen fermentation patterns appears to be the composition of the diet. Murphy et al. (1982) compared the production of VFAs when either soluble carbohydrates, starch, hemicellulose and cellulose were incubated with mixtures of roughage or concentrates. It was found that soluble carbohydrates and starch fermentation parameters were different for the roughage and concentrate diets. The roughage or concentrate mixtures resulted in either 73.0, 21.7, 5.3 and 0.0% or 54.2, 25.3, 18.1 and 2.4%, of acetic, propionic, butyric and valeric acid, respectively, when fed with soluble carbohydrates. There were also differences in the fermentation parameters between hemicellulose and cellulose. Cellulose fermentation produced higher levels of acetate but lower levels of propionic acid than hemicellulose when the two carbohydrates were fermented with either roughage or concentrate mixtures. In general, roughage mixtures produced more acetic but less propionic, butyric and valeric acid than concentrate mixtures when incubated with soluble carbohydrates.

Changes in the diet might be associated with changes in rumen microbial species (Hungate, 1966; Mackie et al., 1978), enzymes in the rumen contents (Baldwin and Palmquist, 1965; Mackie and Gilchrist, 1979) and in the pathways of carbohydrate fermentation (Jayasuriya and Hungate, 1959; Wallnofer et al., 1966).

There are two contrasting views on the effects of different proportions of VFAs on energy utilization by the animal. In a summary of results by different researchers, Blaxter (1962) reported that the relative proportions of acetic, propionic and butyric acid did not

affect their utilization as energy sources for maintenance, but pointed out that their proportional relationships would be important if the animal is fattening. Blaxter (1962) further suggested that there was a causal relationship between the amount of acetate produced and the heat increment of feeding and this resulted in a theory that ruminants had a limited ability to utilize acetate efficiently and that when large quantities of acetate was produced, it was converted to non-productive heat.

Although the theory has been confirmed by other workers (Blaxter, 1980, as quoted by MacRae and Lobley, 1982), contradictory reports have been published (Rook et al., 1963; Orskov and Allen, 1966a; 1966b; Orskov et al., 1979). Orskov et al. (1979) showed that relative proportions of various VFAs did not significantly influence their efficiency of utilization when protein supply was adequate. Recently, MacRae and Lobley (1982) suggested that, since concentrate fed animals produce more propionate than those consuming roughage diets, better performance by concentrate-fed animals might be due to adequate supplies of reduced nicotinamide adenine dinucleotide phosphate (NADPH_2) which would facilitate the conversion of acetate to fat whereas in roughage fed animals, the larger amount of acetate and smaller proportions of propionate would result in a metabolic excess of acetate which would have to be eliminated as heat. Therefore, increasing the absorption of gluconeogenic metabolites to supply NADPH_2 might increase the efficiency of acetate utilization. Such a source of NADPH_2 could well be amino acids as shown by Orskov et al. (1979). More data are obviously required to resolve the controversies about the efficiencies of utilization of the VFAs.

Rate of Passage of Ingesta

Significance of Rate of Passage

Voluntary feed intake is among the main factors influencing animal production (Mott and Moore, 1970), and this is in turn affected by the rate of feed disappearance from the digestive tract. The rate of feed disappearance is a function of ruminal outflow (passage) and the rate of digestion. As the rate of passage of residues from the digestive tract increases, feed intake also increases, leading to the production of more microbial fermentation products since fermentable substrates become less limiting. An increase in the supply of fermentable substrates and rate of passage would be expected to increase microbial growth and passage to the lower digestive tract. An increase in the outflow of microbial protein from the rumen would be expected to increase animal performance due to a rise in the supply of both protein and VFAs.

Although digestibility of feed, at high levels of feed intake, decreases as the rate of passage increases (Van Soest, 1975), the rise in fermentation rate as a result of increased substrate supply would produce more protein and VFAs for a given rumen volume (Hungate, 1966). Nevertheless, excessive passage might worsen the availability of nitrogen for microbial growth if treated preformed protein is the only source of nitrogen (Schmidt et al., 1973), a view which is consistent with the suggestion that supplemental degradable nitrogen sources might be required at high levels of feed intake (Zinn and Owen, 1983). However, excessive rates of passage are unlikely to result in rumen microflora being washed out because the passage rates are considerably below the growth potential of most bacteria (Hungate,

1966). In view of the effects of diet composition and level of feed intake on dry matter (especially fiber) digestibility, it is essential to measure the rate of passage from various feed combinations in order to assess their utilization more objectively. An understanding of factors influencing rate of passage is, therefore, important in the formulation of cattle diets in order to optimize rate of passage and, hence, microbial growth and production.

Factors Affecting Rate of Passage

Rate of passage is affected by the physical form of the diet, level of feed intake, rumination differences among animals, the type of marker used and the composition of the diet. Changing the physical form of the diet by grinding to reduce particle size results in reduced retention time or increased rate of passage (Moore, 1964; Alwash and Thomas, 1971). Rate of passage has also been shown to decrease as feed intake decreases (Balch and Campling, 1965; Grovum and Williams, 1977), indicating that differences in rate of passage among animals might be caused by differences in individual daily feed consumption. Particle size and specific gravity have jointly been considered to dictate the potential exit of feed from the rumen (Balch and Campling, 1965; Welch, 1982) and passage was reported to be maximized with ingesta in the specific gravity range of 1.10 to 1.20 (King and Moore, 1957; Campling and Freer, 1962). However, the cause for the failure of some small particles to pass from the rumen is unknown, although entrapment in the rumen ingesta has been proposed (Welch, 1982). It is also not known whether changes in the rate of passage associated with increased feed intake are due to changes in

the rate of particle reduction by way of rumination or microbial action (Mertens and Ely, 1982).

Differences in rumination activity have been observed between animal species, age, and weight of the animal (Welch and Smith, 1970; 1978); yet rumination is unlikely to be the cause of increased rate of passage that is observed when feed intake rises because rumination time per kilogram of dry matter decreases with increases in dry matter intake (Welch and Smith, 1969; Sudweeks et al., 1980). Therefore, other factors such as increases in rumen motility stimulated by rumen distention might be partly responsible for the increased rate of passage.

The type of marker used in the measurement of rate of passage might also explain variations in the rate of passage. Soluble or small particle markers like polyethylene glycol or chromic oxide, respectively, pass out of the rumen in the liquid phase at a rate which is faster than the passage of fiber (Hungate, 1966). Therefore, it would be expected that as feed intake increases, the rate of passage of the liquid phase would also increase, but at a faster rate than fiber, resulting in an overestimation of ingesta rate of passage. This agrees with the report that chromic oxide overestimates ingesta rate of passage at high levels of feed intake (Beever et al., 1978). If ingesta degradation is considered to be the major factor controlling rate of passage of fibrous feeds, then markers that are intimately associated with fiber (e.g., lignin) would be good indicators of ingesta rate of passage so long as their distribution in the diet is uniform, a condition likely to be satisfied by ground feeds. Uneven distribution of lignin in the forage, for instance,

would tend to underestimate the overall rate of ingesta passage as highly lignified particles would tend to reside longer in the rumen.

Diet composition has also been reported to influence ingesta rate of passage (Eng et al., 1964). Siebert et al. (1976) using sugarcane as a basal diet and fed to steers with either meat meal, Leucaena leucocephala or urea and sodium sulphate, found that the rates of retention of chromium sesquioxide in the rumen were 60.0, 70.2 and 80.7% per day for L. leucocephala, meat meal and urea/sodium sulphate, respectively. The corresponding half-lives were 1.67, 1.96 and 3.22 days ($P = .007$) and digestibility was ranked in the same order (L. leucocephala being the least). Fairhurst (1981) did not find significant differences in the rate of passage of 70% sugarcane diets fed with increasing levels of urea and corn meal, and the average retention time was 38.4 hours. Seibert (1978) found slower rates of chromic oxide passage with sucrose, when sucrose, cellulose and corn meal were compared as energy supplements to a bagasse based diet. The findings of Siebert et al. (1976) are consistent with the established view that the digestibility of a feed decreases as the rate of passage of that feed increases. The results of Seibert (1978) support the view of decreased fiber digestibility caused by high levels of intake of soluble carbohydrates while conflicting with the view that slower rates of feed passage would increase fiber digestibility.

Although the preceding review reflects the importance of rate of passage in animal production, the interpretation of rate of passage measurements should be carried out with caution since their estimation might be affected by the extent to which the portion of the diet,

whose passage is being measured, is intimately associated with the marker being used.

CHAPTER III MATERIALS AND METHODS

A feedlot trial, and six digestibility and nitrogen balance trials were conducted at the Agricultural Research and Education Center at Belle Glade, Florida. The objective for both experiments was to evaluate the effects of carbohydrate and nitrogen source on the utilization of sugarcane diets.

Feedlot Trial

Description of Animals

The trial was conducted for 133 days, starting from October 3, 1981. Thirty six crossbred steers (B. indicus x B. taurus) averaging twelve months old and 239 kg liveweight were used. The steers were removed from St. Augustinegrass (Stenotaphrum secundatum) pastures. They were shrunk for 16 hours(h) without food and water before being weighed and allocated at random to three dietary treatments in a completely randomized design. The three dietary treatments were molasses/cottonseed meal, molasses/urea and corn meal/urea and these were fed as supplements to a sugarcane basal diet.

Formulation of Diets

Three concentrate supplements were formulated to provide 11.0% CP (DM basis) in the total diet when mixed with sugarcane. Total diets comprised of 68% sugarcane and 32% of the supplement on a DM basis. The overall composition of the total diets and the proportions of ingredients used is presented in table 1.

TABLE 1. FORMULATION OF SUGARCANE BASED DIETS CONTAINING VARIOUS CARBOHYDRATE AND NITROGEN SOURCES AND FED TO GROWING STEERS IN THE FEEDLOT (DRY MATTER BASIS)

	Dietary Treatment		
	Molasses/ Cottonseed meal	Molasses/ urea	Corn meal/ urea
	%		
Sugarcane	68.86	68.20	68.70
Molasses (NRC 4-04-696)	11.28	24.32	-
Corn meal (IFN 4-02-849)	-	-	26.35
Cottonseed meal (IFN 5-01-621)	18.82	3.83	1.36
Urea	-	2.07	2.03
Minerals ^a	0.86	0.87	0.83
Salt	0.18	0.18	0.20
Biophos ^b	-	0.53	0.53

^aMinerals contained 11.5% P, 15% Ca, 12.5% salt, .3% Fe, .3% Cu, .02% Co, .2% Mn, .5% Mg, .2% Zn and 80% total mineral.

^bContains 18% Ca and 21% P.

Housing and Feeding of Steers

Steers were housed in a concrete floored covered shed which was divided into six pens measuring 9.8 m x 9.8 m each. Groups of six steers were randomly assigned to the pens and two groups were fed one of the three experimental diets. Steers were fed once daily at 9 a.m. Sugarcane was harvested and chopped every morning with a forage harvester. It was then weighed and placed in the feed troughs and known quantities of molasses or premixed dry concentrate supplement were poured over it. The diets were then thoroughly mixed by hand before allowing the steers to eat. All diets were fed ad libitum and feed refusals were removed and weighed immediately before the next feeding.

Data Collected

Feed intake was calculated from the recorded feed offered and refusals. Feed and orts samples were collected for DM analysis. Dry matter intake was calculated from as-fed feed intake, orts and DM analysis. Final steer weights were calculated from hot carcass weights assuming a 55% hot carcass dress (Goodrich and Meiske, 1971). The initial shrunk weights and the adjusted final weights were used to calculate average daily gains.

Digestibility and Nitrogen Balance Trial

Description of Animals

The trials were conducted from October 5, 1982, to December 17, 1982. Twelve Beefmaster crossbred yearling steers (B. indicus x B. taurus) averaging 13 months of age were used. They were divided into two groups, based on initial weight, for convenience of management and to suit the arrangement of the available experimental facilities. The average weights of steers in group 1 and 2 were 262 and 233 kg, respectively, at the beginning of the experiment. Steers were halter broken during the month preceding the beginning of the experiment.

Housing and Animal Management

Steers were housed in an enclosed barn which provided adequate ventilation and was equipped with individual animal stalls and metabolism crates. Each digestion trial included a 14 day preliminary period to adjust the animals to new rations. The steers spent the first 11 days of the adaptation period in stalls with concrete floors. Three days before the beginning of the collection period, steers were moved from the stalls to metabolism crates. The crates were made of wood except the central part of the floor which was lined with steel

mesh underneath which a urine collection pan was attached. The rear of the crates was open to allow for fecal collection, but had two chains across the open end to retain the steers. At the end of the 7 day collection period, steers were moved to an open yard for two days before repeating the management procedure.

Diet Formulation

Excluding sugarcane and molasses, the remaining diet ingredients were formulated into three concentrate supplements as shown in table 2. The supplements were formulated to give 11.0% CP content in the complete diet. Concentrate supplements were mixed once at the beginning of each trial and stored in covered plastic bins. The remaining supplements at the end of each trial were discarded. In the two diets containing urea, urea supplied 50% of the total dietary nitrogen.

TABLE 2. COMPOSITION OF CONCENTRATE SUPPLEMENT MIXES (DRY MATTER BASIS)

Ingredient	Concentrate Supplement		
	Cottonseed meal	Urea	Corn meal/urea
	%		
Cottonseed meal (IFN 5-01-621)	94.6	46.7	2.1
Corn meal (IFN 4-02-849)	-	-	86.7
Urea	-	30.4	6.4
Minerals ^a	4.5	12.7	2.6
Salt	.9	2.6	.6
Biophos ^b	-	7.6	1.6
Expected CP %	42.0	133.0	30.0

^aMinerals contained 11.5% P, 15% Ca, 12.5% salt, .3% Fe, .3% Cu, .02% Co, .2% Mn, .5% Mg, .2% Zn and 80% total mineral.

^bContains 18% Ca and 21% P.

The complete or total diets were prepared immediately before each feeding. Chopped sugarcane was weighed to comprise 70% of the diet on a DM basis. Molasses was also weighed to give the desired level of DM in the diet, and each supplement was then weighed to give the desired level of supplement DM in the diet. Table 3 shows the proportion of each diet ingredient in the complete diets on a DM basis.

TABLE 3. PROPORTION OF INGREDIENTS IN COMPLETE DIETS (DRY MATTER BASIS)

Ingredient	Dietary Treatment		
	Molasses/ Cottonseed meal	Molasses/ urea	Corn meal/ urea
	%		
Sugarcane	70.00	70.00	70.00
Cottonseed meal (IFN 5-01-621)	16.95	3.00	.65
Molasses (NRC 4-04-696)	12.01	23.31	-
Corn meal (IFN 4-02-849)	-	-	25.68
Urea	-	2.11	2.11
Minerals	.86	.87	.83
Salt	.18	.18	.20
Biophos	-	.53	.53

^aMinerals contained 11.5% P, 15% Ca, 12.5% salt, .3% Fe, .3% Cu, .02% Co, .2% Mn, .5% Mg, .2% Zn and 80% total mineral.

^bContains 18% Ca and 21% P.

Sugarcane was harvested and chopped fresh every morning with a forage harvester and delivered to the barn by 8:30 a.m. The particle size of the chopped sugarcane was approximately 1 cm in length. The sugarcane used in the afternoon feeding was saved from that day's morning harvest.

Experimental Design

A crossover design was used in which steers were allocated at random within each group to three dietary treatments. There were two steers on each treatment during each trial such that a total of twelve observations were obtained for each treatment over the entire experimental period. The arrangement of treatments and allocation of steers to the treatments are shown in table 4, while the analysis of variance table is presented in table 5.

TABLE 4. ALLOCATION OF STEERS TO DIETARY TREATMENTS

Group 1 Steer Number							Group 2 Steer Number						
1	3	5	6	2	4		9	7	11	12	8	10	
Trial 1	A ^a	B	C	C	A	B	Trial 2	B	C	A	A	C	B
Trial 3	C	A	B	A	B	C	Trial 4	A	B	C	B	A	C
Trial 5	B	C	A	B	C	A	Trial 6	C	A	B	C	B	A

^a Treatments: A = Molasses/cottonseed meal
B = Molasses/urea
C = Corn meal/urea

Feeding

Steers were fed twice daily throughout the experiment by 9:30 a.m. and 5:30 p.m. Combined feed ingredients were thoroughly mixed in plastic tubs and either fed straight from the tubs while steers were in the stalls or placed in the feed-bunks attached to the metabolism crates. During the adaptation period, voluntary feed intake by each steer was measured to determine the amount of feed that would be offered during the collection period. The amount of feed offered allowed for 5 to 10% feed refusals and the amount fed was kept constant during the collection period.

TABLE 5. ANALYSIS OF VARIANCE TABLE USED TO ANALYZE DATA OBTAINED DURING DIGESTION TRIALS WITH STEERS FED EITHER MOLASSES/COTTONSEED MEAL, MOLASSES/UREA OR CORN MEAL/UREA

ANOVA	
Source	Degrees of Freedom
Treatment	2
Group	1
Treatment x Group	2
Trial (Group)	4
Animal (Group)	10
Error	16
Total	35

Rate of Passage

Chromic oxide (Cr_2O_3) was used as a feed marker in these trials. On the first day of each collection period at 6 a.m., 100 g of Cr_2O_3 powder was mixed thoroughly with a portion of feed and offered to each steer. In trial 1, Cr_2O_3 was mixed with 454 g of corn meal and offered to each steer. Intake, especially for steers whose rations did not include corn meal, was poor so that 371 g of the previous day's sugarcane was offered to all steers to stimulate the intake of the marked feed. A further 227 g of sugarcane was fed to steers Nos. 1 and 2. In subsequent trials (2 to 6), approximately 2 kg (fresh basis) of the complete diet were withheld from each steer on the previous evening before the start of the trial to ensure increased appetite and rapid consumption of the marked feed. The Cr_2O_3 was mixed with a 1.0 kg portion of the complete diet at 6:00 a.m. Thirty minutes were allowed for the consumption of the marked feed and the

remaining feed was removed and the feed troughs were then thoroughly washed of any residual Cr_2O_3 in preparation for that day's a.m. feeding. Total fecal collection began 6 h after feeding the marker.

Weighing of Steers

Steers were weighed at the beginning of the adaptation period of each trial and at the end of the collection period.

Sampling Procedure

A 150 to 200 g sample of chopped sugarcane was taken at each feeding from the storage bunk, and a 150 g sample of the complete diet was obtained immediately before being offered to each steer at each feeding. On a daily basis, the two sugarcane samples and samples obtained for each complete diet were combined. All samples were refrigerated at 5° C for subsequent processing. The concentrate supplements were sampled once at the beginning of each trial. Molasses was sampled twice during the experimental period.

Orts were collected and weighed before each feeding. Approximately 150 g were sampled from refusals exceeding 150 g whereas all refusals were sampled if they weighed less than 150 g.

Collection of Fecal Samples

Total fecal collections were made every 6 h during the first 3 days of the collection period and every 12 h for the remaining 4 days (Seibert, 1978; Fairhurst, 1981). Feces from each steer were weighed, thoroughly mixed, a 5% aliquot taken and stored in a refrigerator at 5° C. The aliquots from each steer were composited at each sampling with the previously stored ones for further processing. Approximately 4 to 5 g of thymol were added daily to the fecal samples

as an anti-fungal agent. A 100 g fecal sample was taken from each steer for Cr_2O_3 analysis and immediately dried at 80°C .

Collection of Urine

Total urine collections were made every 24 h in large glass bottles fitted with a urine collection pan and funnel attached under each crate. Total urine was measured and a 5% aliquot was taken daily from each steer, composited with previous collections and stored in a refrigerator. Fifty ml of 50% H_2SO_4 were added to the collection bottles to prevent NH_3 vaporization.

Collection of Rumen Fluid

One sample of rumen fluid was obtained with a stomach tube from each steer at the end of each trial 3 to $3\frac{1}{2}$ h after the morning feeding. Each sample was measured for pH after straining through a cheese cloth. One ml of saturated HgCl_2 was added to each sample to stop microbial action. With the exception of Trial 1, rumen fluid was adjusted to pH 4 with 10N H_2SO_4 to prevent NH_3 loss. The quantities of acid added were recorded and samples were frozen for future analyses.

Collection of Blood

Twenty ml of blood were obtained from the jugular vein of each animal at the end of each trial using heparinized vacutainer tubes immediately before the collection of rumen fluid. Tubes were then rolled gently from side to side to mix the heparin with blood. Blood was stored in a refrigerator until it was centrifuged about 5 h later to obtain plasma. Plasma was then stored in a freezer until analyzed.

Preparation of Samples for Analysis

Samples of complete diets, sugarcane and orts were each mixed thoroughly, and a subsample of about 200 g was obtained and dried for 48 h at 60° C in a forced-air oven. The samples were then allowed to equilibrate to room conditions for 24 h before weighing (air-dry weight).

The composited fecal samples from each steer were thoroughly mixed and two 300 g samples were taken, dried at 60° C in a forced-air oven for 48 h, air equilibrated for 24 h and reweighed. Fecal samples for Cr_2O_3 analysis were dried in a forced-air oven for 72 h at 80° C and weighed immediately for DM determination (Lambourne, 1957).

All feed, sugarcane, orts and fecal samples were ground in a Thomas Wiley mill to pass a 1 mm pore size. Samples were then stored in Whirl-pac bags until analyzed. A sample of each feed refusal was subsampled on a percentage basis of the total refusal for each steer. The subsamples were then composited, mixed thoroughly and stored in Whirl-pac bags until analyzed.

At the end of each trial, about 20 ml of composited urine samples were centrifuged at 1800 rpm for 15 minutes to remove any foreign matter. Fifteen ml of supernatant was then taken and stored in plastic test tubes in a freezer.

Analysis of Samples

Samples of feed, sugarcane, orts and composite feces were analyzed for DM, ether extract (EE), crude fiber (CF), CP and ash according to the methods outlined in A.O.A.C. (1970). Nitrogen free extract (NFE) was obtained by difference. Acid detergent fiber (ADF), neutral detergent fiber (NDF), cellulose and permanganate lignin were

analyzed according to the procedures of Goering and Van Soest (1970) and Van Soest and Wine (1967). Urine nitrogen was determined (using .2 ml of urine) by the Micro-Kjeldahl technique (A.O.A.C., 1970).

Chromic oxide was analyzed according to the methods of Kimura and Miller (1957) modified by digesting organic matter in the sample with nitric acid and then boiling the sample to dryness before oxidizing it further with 70% perchloric acid.

Rumen fluid was centrifuged immediately before each analysis and analyzed for acetic, propionic, butyric, isovaleric and valeric acid using Gas Liquid Chromatography. The column for the VFAs was packed with 20% neopentyl glycol succinate plus 2% phosphoric acid on Chromosorb W (A/W, DMCS, 60-80 mesh). Rumen fluid ammonia was determined by the Technicon Autoanalyzer and plasma glucose was analyzed by using a Glucose Assay Kit (Sigma Chemical Co., 1982).

Statistical Analysis

The metabolism experiment was analyzed as a complete crossover design (Henderson, 1969) having a total of twelve observations per treatment, while feedlot data were analyzed using analysis of variance procedures of a completely randomized design.

CHAPTER IV RESULTS AND DISCUSSION

Feedlot Trial

The average daily gains of steers consuming the molasses/urea diet was lower ($P < .05$; table 6) than that by steers fed either the molasses/cottonseed meal or corn meal diets which were similar. Dry matter (DM) intake by steers fed molasses/cottonseed meal was slightly higher ($P > .05$) than DM intake by steers fed the two diets containing urea, which were similar. Steers fed the molasses/urea diet had a 28% higher ($P > .05$) DM intake to gain ratio than steers fed either the molasses/cottonseed meal or corn meal/urea diets (table 6). Since DM intakes were similar, the lower performance by steers fed the molasses/urea diet is a reflection of poorer utilization of the diet as shown by the high DM intake to gain ratio of 11.4 compared with a ratio of 8.9 for the other two diets. Both a decreased net energy intake for gain (NEg) and a decreased supply of metabolizable protein might have been responsible for the reduced performance of steers fed the molasses/urea diet.

The predicted net energy (NE) for maintenance for the molasses/cottonseed meal, molasses/urea and corn meal/urea diets were 1.45, 1.43 and 1.53 Mcal/kg DM, respectively, using a NE for maintenance of 1.33 for sugarcane ((McDowell et al., 1974; Ensminger and Olentine, 1978), 1.91 for molasses, 1.69 for cottonseed meal and 2.28 for corn meal (NRC, 1976). The NE intake for maintenance (NE_m) were similar among the dietary treatments ($P > .05$; table 6). The

TABLE 6. PERFORMANCE OF STEERS FED FEEDLOT DIETS CONTAINING HIGH LEVELS OF SUGARCANE AND SUPPLEMENTED WITH DIFFERENT SOURCES OF CARBOHYDRATE AND NITROGEN

Item	Dietary Treatment		
	Molasses/Cotton seed Meal	Molasses/Urea	Corn meal/Urea
Number of steers	12	12	12
Initial weight (kg)	239	239	241
Final weight (kg)	339	315	335
Average daily gain (kg)	.75 ^a	.57 ^b	.71 ^a
Dry matter intake (kg/day)	6.66 ^a	6.37 ^a	6.29 ^a
Dry matter:gain ratio	8.88 ^a	11.38 ^a	8.86 ^a
NEg ^c intake Mcal/kg day	5.40 ^a	5.22 ^a	5.38 ^a
NEg ^d intake Mcal/kg day	2.47 ^a	2.23 ^a	2.49 ^a

^{a,b} Values in the same row followed by different superscripts are different ($P < .05$)

^c Net energy for maintenance

^d Net energy for gain

NEg (obtained from the same sources as NE for maintenance) were also similar ($P > .05$; table 6), but steers fed the molasses/urea diet had a 10% lower NEg than steers fed the other two diets. Therefore, the poorer performance of steers fed molasses/urea could partly be explained by the lower NEg.

Poor performance by animals fed sugarcane based diets supplemented with either molasses/urea or urea alone has been reported by other workers (Siebert et al., 1976; Ferreiro et al., 1977; Rodriguez et al., 1978). Low animal performance on such diets was frequently attributed to a reduced supply of metabolizable protein or amino acids and glucose precursors. The supply of glucose per se, as a major

limiting metabolite for growth could be eliminated since equivalent amounts of energy in the form of acetic or propionic acid produced similar growth rates to glucose in lambs (Preston, 1982). Imbalances in amino acid supply can also be eliminated as a factor, since Conrad and Hibbs (1968) reported that the amino acid composition of rumen microorganisms did not vary widely with different diets. Hence, low total amino acid supply might be responsible for the decreased performance by steers fed the molasses/urea diet.

Preston and Willis (1974) and Preston and Leng (1978) reported that the rate of animal performance is a function of the amount of true protein (of low rumen degradability) fed when animals are fed sucrose based diets (molasses or sugarcane) supplemented with urea. Other studies showed that the substitution of natural protein by urea in forage diets low in protein usually resulted in lower weight gains by cattle (Briggs et al., 1947; Dining et al., 1949; Watson et al., 1949; Kirk, 1952). Kirk (1952) reported that the substitution of citrus pulp and urea for 40% of the cottonseed meal in the diet increased the amount of feed required per unit of gain. The above studies imply that the supply of amino acids were responsible for the reduced animal performance when NPN was fed with molasses and this is consistent with the results obtained with the molasses/urea diet (table 6).

The steers fed corn meal/urea, even though they were fed similar amounts of urea as steers fed molasses/urea diet, possibly converted more urea nitrogen to microbial protein due to the creation of conditions more favorable for microbial protein synthesis induced by starch in the corn meal (Mills et al., 1942; 1944; Belasco, 1956) than sugar in molasses. The contribution of bypass protein from corn

meal would be disregarded because corn meal contributed only 20% of the dietary crude protein, of which only 8% would bypass ruminal fermentation (Satter and Roffler, 1977). Steers fed the corn meal/urea diet used in this study had similar gains to steers fed a similar diet used in a study which evaluated different levels of urea (Fairhurst, 1981), indicating that animal production from this diet was near maximum under South Florida conditions. The superior performance of steers fed molasses/cottonseed meal diet over those fed the molasses/urea diet, both of which contained soluble sugars as the supplemental energy source, also suggests that the supply of metabolizable protein or amino acids was inadequate with the molasses/urea diet. The similarity in animal performance, in terms of average daily gain and feed utilization (table 6), between molasses/cottonseed meal and corn meal/urea diets indicates that starch (as in corn meal) fed with NPN (urea) can be used to substitute for natural protein in sugarcane based diets.

In summary, it appears that the poor performance by steers consuming molasses/urea diet was caused by a shortage of both NEg and metabolizable protein.

Digestibility and Nitrogen Balance Trial

The condition of the steers was good throughout the trials except for steers consuming the molasses/urea diet which showed sporadic clinical signs of restlessness, kicking aimlessly, inappetance, excessive salivation and scouring. Uneasiness and excessive salivation by steers are early clinical signs of urea toxicity caused by high levels of NH_3 in the blood (Reid, 1953; Chalupa, 1968). Although excessive salivation and uneasiness have been reported for steers consuming diets comprising of more than 50% molasses (DM

basis)(Preston et al., 1968; Creek et al., 1974; Pathak and Ranjhan, 1976), molasses toxicity was unlikely in the present study because it comprised only 23.3% of the DM of the molasses/urea diet. A lack of the above clinical signs by steers fed the corn meal/urea diet indicates that NH_3 evolved from urea hydrolysis was being captured more efficiently by rumen microorganisms when corn meal was fed than when molasses was fed.

The overall weight gains by steers consuming molasses/cottonseed meal, molasses/urea and corn meal/urea diets were .75, .03 and .40 kg/day, respectively. The individual liveweight changes for steers in each trial are presented in table 7. Although the liveweight changes of steers reported for the metabolism trials were for 21 day periods, they had a similar ranking with respect to dietary treatment to the feedlot data reported earlier. However, steers fed the corn meal/urea diet had much lower gains than steers fed the molasses/cottonseed meal during the metabolism trial than during the feedlot trial. Poor performance by steers during the initial weeks of feeding urea with sugarcane based diets has been reported (Siebert et al., 1976; Silvestre et al., 1977a; Fairhurst, 1981). Fairhurst (1981) reported only .12 kg/day liveweight gain for steers consuming a sugarcane based diet similar to the corn meal/urea diet used here, compared with .68 kg/day for steers fed a cottonseed meal diet during the first 30 days of a feedlot trial. Siebert et al. (1976) also reported poor initial (57 days) gains by steers fed fresh sugarcane diets supplemented with a urea-sodium sulphate solution providing about 70% of the crude protein as urea. Both Fairhurst (1981) and Siebert et al. (1976) attributed poor performance to the need for adaptation to urea feeding since both workers reported improved liveweight gains with increasing

TABLE 7. STEER INITIAL AND FINAL WEIGHTS FOR EACH TRIAL

Steer Number	Group 1					
	Trial 1		Trial 3		Trial 5	
	Initial	Final	Initial	Final	Initial	Final
1	268 ^a (A) ^b	284	284(C)	291	291(B)	295
2	255(A)	270	270(B)	257	257(C)	266
3	277(B)	286	286(A)	293	293(C)	291
4	252(B)	266	266(C)	264	264(A)	282
5	261(C)	266	266(B)	264	264(A)	280
6	259(C)	273	273(A)	295	295(B)	305

Steer Number	Group 2					
	Trial 2		Trial 4		Trial 6	
	Initial	Final	Initial	Final	Initial	Final
7	220(C)	236	236(B)	241	241(A)	252
8	230(C)	220	220(A)	239	239(B)	230
9	205(B)	207	207(A)	214	214(C)	214
10	259(B)	268	268(C)	284	284(A)	291
11	250(A)	245	245(C)	248	248(B)	248
12	234(A)	239	239(B)	215	215(C)	232

^a All figures are in kg

^b Letter in parenthesis refers to dietary treatment where
 A = Molasses/cottonseed meal
 B = Molasses/urea
 C = Corn meal/urea

time on feed. Although steers consuming the molasses/urea diet during the metabolism trials had a lower DM intake (discussed later), the difference was not enough to explain the large difference in liveweight gain. Therefore, adaptation to urea feeding might have been a factor in reducing liveweight gains since the 21 day period used was even shorter than the time periods reported in other studies.

Chemical composition of sugarcane, molasses, concentrate supplements and total diets are presented in tables 8, 9, 10 and 11, respectively. The average DM content of sugarcane was 25.9%, ranging from 24.5% at the beginning of the trials to 27.3% during the fifth trial. Crude protein content of the sugarcane varied very little during the experimental period with a mean of 4.0%. Crude fiber (CF), NDF, ADF, cellulose, and lignin of sugarcane varied slightly between and among trials although there was a tendency for the fiber components to decline towards the end of the three month study (table 8). The relatively uniform quality of sugarcane during the study period indicates that sugarcane had attained physiological maturity by the time trials were started. The tendency for slight increases in DM and a decline in the fiber fraction of the plant are indicative of an increase in the sucrose content of the sugarcane stalk (Pate, 1979).

The DM content of the experimental diets was similar, but the crude protein content of the molasses/cottonseed meal and molasses/urea diets was slightly lower than anticipated (table 11). The molasses/urea diet had the lowest level of fiber components, mainly because of molasses and urea. The molasses/cottonseed meal and corn meal/urea diets had a similar level of fiber components.

TABLE 8. CHEMICAL COMPOSITION OF SUGARCANE USED IN METABOLISM TRIALS
(DRY MATTER BASIS)

Component	Trial Number						Mean
	1	2	3	4	5	6	
Dry matter	24.5	25.7	25.7	26.5	27.3	25.8	25.9
Organic matter	95.7	96.9	96.9	97.2	97.4	96.9	96.8
Crude protein	4.4	3.9	3.7	3.9	3.6	4.3	4.0
Ether extract	.63	1.37	1.26	.47	1.15	1.23	1.0
Crude fiber	25.3	25.2	27.0	25.9	24.1	23.0	25.1
NDF ^a	51.0	50.5	51.0	51.7	49.9	47.7	50.3
ADF ^b	32.7	33.4	33.7	32.5	32.3	31.5	32.7
Cellulose	25.6	24.9	25.5	25.0	24.8	24.0	25.0
Lignin	6.5	6.7	7.2	6.5	7.0	6.5	6.7

^a Neutral detergent fiber

^b Acid detergent fiber

TABLE 9. CHEMICAL COMPOSITION OF MOLASSES
(DRY MATTER BASIS)

Component	% Composition
Dry matter	77.2
Organic matter	89.9
Crude protein	6.7

TABLE 10. CHEMICAL COMPOSITION OF DRY CONCENTRATE SUPPLEMENTS USED IN METABOLISM TRIALS (DRY MATTER BASIS)

Component	Concentrate Supplement		
	Molasses/Cotton- seed Meal	Molasses/Urea	Corn Meal/Urea
	%		
Dry matter	88.7	89.7	85.9
Organic matter	89.6	80.0	94.7
Crude protein	42.8	113.3	30.1
Ether extract	1.4	3.3	2.5
Crude fiber	10.8	5.4	1.9
NDF ^a	39.0	35.8	41.0
ADF ^b	19.4	10.7	4.0
Cellulose	13.9	7.4	2.7
Lignin	4.7	2.4	.8

^a Neutral detergent fiber

^b Acid detergent fiber

TABLE 11. AVERAGE CHEMICAL COMPOSITION OF TOTAL EXPERIMENTAL DIETS
(DRY MATTER BASIS)

Component	Dietary Treatments		
	Molasses/Cotton- seed Meal	Molasses/Urea	Corn Meal/Urea
	%		
Dry matter	32.4	32.3	31.6
Organic matter	94.5	93.9	96.4
Crude protein	10.4	10.6	11.4
Ether extract	.9	.8	1.3
Crude fiber	18.3	17.0	18.4
NDF ^a	39.0	35.8	41.0
ADF ^b	26.2	23.1	25.5
Cellulose	5.4	4.7	5.3
Lignin	19.9	17.6	19.5

^a Neutral detergent fiber

^b Acid detergent fiber

The DM intake and digestibility coefficients for each steer in each trial are presented in appendix tables 18 through 23, while the means for the dietary treatments are given in table 12. The DM intake of steers offered molasses/urea diet was lower than that of steers given molasses/cottonseed meal ($P < .02$), but similar to the DM intake of steers fed corn meal/urea.

The lower DM intake by steers fed urea containing diets than for steers fed cottonseed meal agrees with the general observation made with the feedlot data (table 6) and this can be ascribed to the presence of urea in the two diets (tables 1 and 3). Urea has been shown to decrease DM intake when fed at levels above 2% of the DM (Lassiter et al., 1958; Kertz and Everett, 1975; Fairhurst, 1981). However, a lack of significant differences in DM intake by steers fed either molasses/cottonseed meal or corn meal/urea diets suggests that corn meal might have partially offset the negative effects of urea on feed intake. A possible effect of corn meal on DM intake might be to increase rumen turnover and flow of liquid from the rumen. Priego et al. (1977) reported that the addition of bypass nutrients to feeds sufficient in fermentable carbohydrates (sucrose in sugarcane) increased rumen turnover which resulted in increased flow of liquid from the rumen. Therefore, increased performance by animals fed sugarcane diets supplemented with bypass nutrients might be mediated through improved DM intake, microbial efficiency and supply of undegraded nutrients like amino acids and starch to the lower digestive tract.

Digestibility coefficients for DM and organic matter (OM) were highest for steers fed the molasses/urea diet ($P < .05$ and $P < .03$, respectively) but steers fed molasses/cottonseed meal and corn

TABLE 12. DRY MATTER INTAKE AND APPARENT DIGESTIBILITY COEFFICIENTS OF STEERS FED SUGARCANE BASED DIETS SUPPLEMENTED WITH DIFFERENT SOURCES OF CARBOHYDRATE AND NITROGEN

Component	Dietary Treatment			SE
	Molasses/Cotton-seed Meal	Molasses/Urea	Corn Meal/Urea	
DM intake, kg/day	4.7 ^g	4.1 ^h	4.3 ^{d,e}	.1
Digestibilities, %				
Dry matter	64.9 ^h	67.0 ^g	65.7 ^{g,h}	.6
Organic matter	65.7 ^h	68.0 ^g	67.0 ^{g,h}	.5
Crude protein	56.7 ^h	61.1 ^g	64.7 ^g	1.2
Ether extract	23.8 ^g	31.8 ^g	44.1 ^g	11.5
Crude fiber	41.4 ^g	44.0 ^g	44.4 ^g	1.1
NFE ^a	73.8 ^h	75.6 ^g	73.8 ^h	.4
NDF ^b	37.0 ^g	38.2 ^g	40.4 ^g	1.6
ADF ^c	39.9 ^g	40.5 ^g	42.8 ^g	1.5
Cellulose	46.0 ^g	45.1 ^g	48.0 ^g	1.0
Lignin	17.0 ^g	14.6 ^g	21.8 ^g	2.1
ME ^d	10.54	8.72	10.08	.36
NEm ^e	4.98	4.93	4.90	.02
NEg ^f	1.07	.52	.99	.12

^a Nitrogen free extracts

^b Neutral detergent fiber

^c Acid detergent fiber

^d Metabolizable energy intake (Mcal/day)

^e Net energy intake for maintenance (Mcal/day)

^f Net energy intake for gain (Mcal/day)

^{g,h} Values in the same row with different superscripts are different (P < .05)

meal/urea diets had similar DM and OM digestibilities (table 12). The differences in DM and OM digestibility coefficients appear to be caused mainly by the lower digestibility of cottonseed meal, and a higher DM intake by steers offered the molasses/cottonseed meal diet which would decrease feed digestibility.

The molasses/urea diet had the highest nitrogen free extract (NFE) digestibility coefficient ($P < .02$) while NFE digestibility coefficients for molasses/cottonseed meal and corn meal/urea diets were similar. The presence of highly digestible molasses and urea in the molasses/urea diet was responsible for the high NFE digestibility.

There were no differences ($P > .05$) among dietary treatments in the digestibility coefficients of CF, NDF, ADF, cellulose and lignin (table 12 and the probability values are presented in table 13), although the corn meal/urea diet tended to have higher digestibility coefficients than the molasses/cottonseed meal and molasses/urea diets.

Data reported by other workers (Mitchell et al., 1940; Hamilton, 1942; Burroughs et al., 1950; Fontenot et al., 1955; Hungate, 1966; Chappel and Fontenot, 1968; Martin et al., 1981) indicated that the consumption of high levels of readily fermentable carbohydrates, as in sugarcane and molasses, decreased fiber digestibility. The diets used in this study contained high levels of readily fermentable carbohydrates ($> 45\%$) with approximately 40% of the fermentable carbohydrates coming from sugarcane alone. Therefore, a lack of differences ($P > .05$) among the dietary treatments would largely be ascribed to the presence of the high levels of sugars in all the diets used. The sugars from sugarcane might have caused a general decline in fiber digestion, enough to eliminate the dietary treatment effects.

TABLE 13. PROBABILITY VALUES OF THE ANALYSIS OF VARIANCE OF THE DRY MATTER INTAKE, DIGESTIBILITY COEFFICIENTS AND INTERACTIONS

Component	Treatment	Group	Treatment * Group
DM intake ^a	.0208	.0003	.5356
Digestibilities:			
Dry matter	.0551	.0467	.7235
Organic matter	.0284	.0528	.7727
Crude protein	.0013	.2605	.7191
Ether extract	.4677	.2684	.1659
Crude fiber	.1295	.0047	.0612
NFE ^b	.0169	.1615	.2329
NDF ^c	.3302	.0076	.9159
ADF ^d	.3906	.0178	.9743
Cellulose	.1732	.0014	.9739
Lignin	.0687	.0086	.4459

^a Dry matter intake

^b Nitrogen free extract

^c Neutral detergent fiber

^d Acid detergent fiber

The slightly higher ($P > .05$) NDF, ADF and cellulose digestibility coefficients obtained with corn meal/urea diet than with the molasses/cottonseed meal and molasses/urea diets might be attributed to corn meal. The starch in corn meal might have reduced the inhibitive effect of sugars on fiber digestibility, as indicated by Seibert (1978), after removing the influence of the digestibility of the fibrous components of the energy supplements from total NDF digestibility in diets based on bagasse.

A lack of differences ($P > .05$) in the digestibility of fiber components (table 12) between dietary treatments in the present study also indicates that the source of nitrogen did not influence fiber digestibility. These results support other reports which showed that nitrogen supplementation, and not the source of nitrogen, influences the digestibility of organic matter or fiber when it is used to correct a nitrogen deficiency of the diet (Gallup et al., 1952; Head, 1953; Gallup et al., 1954; Fairhurst, 1981). Improved fiber digestibility ascribed to the source of nitrogen, might be expected if the nitrogen source is also used to supply readily fermentable carbohydrates (like most plant proteins) in diets low in both readily fermentable carbohydrates and nitrogen, as in most poor quality hays. An extreme case where nitrogen source might influence fiber digestibility is when the nitrogen source is treated to reduce its availability in the rumen (Schmidt et al., 1973). The diets used in the present study were high in readily fermentable carbohydrates and the nitrogen sources were not treated.

The NEm were similar among the dietary treatments ($P > .05$; table 12) while the NEg was lower ($P < .01$) for the molasses/urea diet than for the other two diets which were similar (table 12). The

metabolizable energy (ME) intake was also lower ($P < .007$) for the molasses/urea diet than for the other two diets (table 12). The lower NEg and ME intake by the molasses/urea-fed steers appeared to be related to a lower DM intake by the same steers (table 12).

Crude protein digestibility data are presented in table 12, while other nitrogen metabolism data for individual steers are given in appendix tables 24 through 29 and data for average nitrogen metabolism for the three dietary treatments are shown in table 14.

Nitrogen intake by the steers was lowest ($P < .05$) for the molasses/urea diet but similar for the molasses/cottonseed meal and corn meal/urea diets (table 14). The low nitrogen intake by steers fed the molasses/urea diet corresponds with the low DM intake (table 12), already discussed for this dietary treatment, and the lower CP content of this diet (table 11).

Crude protein digestibility (table 12) or the apparent nitrogen digestibility (table 14) was lower for the molasses/cottonseed meal diet than for the molasses/urea and corn meal/urea diets ($P < .03$). The poorer digestibility of CP and nitrogen for the molasses/cottonseed meal diet than for the two urea diets is mainly due to cottonseed meal being incompletely degraded in the rumen, while urea was completely hydrolyzed to NH_3 and absorbed. Therefore, some cottonseed meal bypassed rumen fermentation into the lower digestive tract where further digestion of the cottonseed meal nitrogen was also incomplete, leading to the approximate 50% rise in dietary fecal nitrogen excretion over the two urea diets ($P < .0005$; table 14).

Although nonsignificant, apparent nitrogen digestibility for the molasses/urea diet was lower than the apparent nitrogen digestibility for the corn meal/urea diet. Molasses has been reported to decrease

TABLE 14. NITROGEN METABOLISM DATA OF STEERS FED SUGARCANE BASED DIETS SUPPLEMENTED WITH DIFFERENT SOURCES OF CARBOHYDRATE AND NITROGEN

Component	Dietary Treatments			SE
	Molasses/Cotton- seed Meal	Molasses/ Urea	Corn meal/ Urea	
N intake (g/day) ^a	78.4 ⁱ	68.1 ^j	78.2 ⁱ	3.1
Fecal N (g/day) ^b	33.9 ⁱ	26.0 ^j	27.3 ^j	1.2
Metabolic fecal N (g/day) ^c	23.5 ⁱ	20.5 ^j	21.5 ^j	.6
Urine N (g/day) ^d	25.6 ⁱ	30.0 ⁱ	29.3 ⁱ	1.8
Apparent N digestibility (%) ^e	57.8 ^j	61.8 ⁱ	65.1 ⁱ	2.3
True N digestibility (%) ^f	86.7 ^j	91.5 ⁱ	92.5 ⁱ	.8
Digested N retained (%) ^g	40.6 ⁱ	20.7 ⁱ	40.3 ⁱ	6.6
N balance (g/day) ^h	18.9 ⁱ	12.1 ⁱ	21.6 ⁱ	2.8

^a N intake = [(N content diet)(amount diet offered)] - [(Amount, orts) (N content orts)]

^b Fecal N = (N content feces)(fecal output)

^c Metabolic fecal N = (DM intake x .005); (Maynard et al., 1979)

^d Urine N = (Urine volume)(N content of urine)

^e Apparent N digestibility = [(N intake - Fecal N) ÷ N intake] x 100

^f True N digestibility = [(N intake - Fecal N + Metabolic fecal N) ÷ N intake] x 100

^g Digested N retained = [(N intake - Fecal N - Urinary N) ÷ (N intake - Fecal N)] x 100

^h N balance = N intake - (Fecal N + Urinary N)

^{i,j} Values in the same row with different superscripts are different (P < .05)

the apparent digestibility of nitrogen (Briggs and Heller, 1943; Foreman and Herman, 1953; Bohman et al., 1954). Molasses has also been reported to depress the apparent digestibility of nitrogen even in diets containing most of their nitrogen as urea (Martin, 1975; Martin et al., 1981). Pate (1983) suggested that the cause for depressed apparent nitrogen digestibility might be that molasses partially inhibits the digestion of preformed or microbial protein leaving the rumen, although the mechanisms by which this inhibition occurs was not explained. Since nitrogen intake by steers fed the molasses/urea diet was the lowest (table 14), the similarity in both fecal ($P > .05$) and metabolic fecal ($P > .05$) nitrogen excretion for the steers fed molasses/urea and corn meal/urea diets seems to support the view that molasses might indeed be inhibiting nitrogen digestibility. One possible explanation for the inhibition would be a reduced digestibility of the microorganisms that proliferate on diets containing molasses, and another one might be reduced digestibility of molasses nitrogen. The NRC (1968) suggested a CP digestibility of 28% for molasses and 78% for corn. These differences in the digestibility of the CP of the energy supplements of the diets containing urea would account for most of the differences in nitrogen digestibility of the molasses or corn meal containing diets. The above mentioned explanations for reduced nitrogen digestibility with molasses diets might have also partially contributed to the lower apparent nitrogen digestibility coefficients for the molasses/cottonseed meal diet.

Urinary nitrogen excretion was similar ($P > .10$) for all dietary treatments, although steers fed molasses/urea and corn meal/urea diets tended to lose more nitrogen in their urine than those fed molasses/cottonseed meal diet (table 14). Such a tendency is consistent with

the higher apparent nitrogen digestibilities for the urea containing diets discussed earlier. Considering the lower nitrogen intake by steers consuming the molasses/urea diet (table 14), a similar urinary nitrogen loss by those steers to that of steers consuming larger amounts of nitrogen in the other two diets, implies that a greater proportion of nitrogen consumed was lost as urinary nitrogen when urea was fed with molasses. A possible cause of increased urinary nitrogen losses by steers would be the rapid absorption and excretion of NH_3 from urea degraded in the rumen. Immediately after feeding diets containing urea, the rate of NH_3 generation might have exceeded the rate at which it was being incorporated into microbial protein (Pearson and Smith, 1943b; Bloomfield et al., 1960) resulting in a rapid increase in the amount of NH_3 absorbed from the rumen and excreted in the urine (Lewis, 1957; Chalupa, 1972).

The digested nitrogen retained (%) was not different ($P > .08$) for steers fed the molasses/cottonseed meal, molasses/urea and corn meal/urea diets (table 14). Nitrogen balance was also not different ($P > .07$) for the three dietary treatments (table 14). However, both the digested nitrogen retained and nitrogen balance of steers fed molasses/urea diet were much lower than these measures for the other two diets. Steers fed the molasses/urea diet depended largely on microbial protein for their supply of metabolizable protein. Since the biological value of microbial protein is considered to be similar over a wide range of feeds (Conrad and Hibbs, 1968), the reduced digested nitrogen retained and nitrogen balance by steers fed the molasses/urea diet is indicative of increased urinary nitrogen losses mainly from the NH_3 absorbed from the rumen rather than from the catabolized absorbed amino acids.

The higher percentage of digested nitrogen retained and nitrogen balance, though nonsignificant, by steers consuming the corn meal/urea diet than of those fed the molasses/urea diet, indicated that corn meal stimulated higher microbial protein synthesis than molasses. Other studies have shown that starch, as in corn meal, gave greater urea utilization than molasses (Bell et al., 1953; Martin et al., 1981) or cellulose (Belasco et al., 1956). The close similarity of nitrogen retention data for the molasses/cottonseed meal and corn meal/urea diets indicates that NPN can effectively replace plant protein when fed with a suitable source of carbohydrate such as starch. The nitrogen balance data generally support the growth data by steers on the feedlot trial discussed earlier in this chapter. The major cause of poor animal performance when molasses/urea diets are fed to beef cattle (Ferreiro and Preston, 1976a; Silvestre et al., 1976; 1977a) or dairy cows (Lofgreen and Otagaki, 1960b; Owen et al., 1967) could be an inadequate intake of energy and supply of metabolizable protein as shown by the low utilization of nitrogen in the present study (table 14).

Rumen NH_3 levels were determined to assess whether NH_3 nitrogen supply might have limited microbial growth and, hence, fermentation in general. Rumen NH_3 concentration for individual steers ranged from 0 to 20.1 mg/100 ml of rumen fluid in comparison to values ranging from 0 to 130 mg/100 mg of rumen fluid reported in the literature (Hungate, 1966; Church, 1976). The mean rumen fluid NH_3 levels were $1.63 \pm .59$, 4.39 ± 1.01 and 5.94 ± 1.76 mg/100 ml for the molasses/cottonseed meal, molasses/urea and corn meal/urea diets,

respectively, but the differences between treatments were not significant. Satter and Roffler (1977) suggested that 5 mg of NH_3 nitrogen per 100 ml rumen fluid was approximately the upper level for maximum dietary nitrogen utilization. Only those values obtained for molasses/urea and corn meal/urea diets in this study were close to the stated upper level while those for molasses/cottonseed meal were below that level. However, all the values for NH_3 nitrogen concentration were below the 23.5 mg/100 mg rumen fluid found by Mehrez et al. (1977) to be the optimum for microbial ruminal fermentation. Although the preceding discussion suggests a deficiency of NH_3 nitrogen with the diets used in the present study, the lower nitrogen balance data along with high urinary nitrogen losses for the molasses/urea diet implies that the optimum NH_3 nitrogen level for maximum urea utilization is below the stated 5 mg NH_3 nitrogen per 100 ml of rumen fluid.

Using Cr_2O_3 excretion data presented in figure 1, retention time, 5% and 5 to 80% Cr_2O_3 excretion times were calculated (table 15). Figure 2 shows Cr_2O_3 excretion pattern at six hour intervals after feeding the marker. Retention time was calculated by the method of Castle (1956) that gives the properties of the excretion curve (Figure 1) into single numerical values which can then be used to compare the different Cr_2O_3 excretion curves in figure 1. The excretion times for 5% and 5 to 80% Cr_2O_3 excretion are based on the proposition that the time required for the feed to pass through the omasum, abomasum and the intestines can be estimated by the time required for 5% of the feed marker to be excreted in the feces, and that the excretion of 5 to 80% of the marker is indicative of the time taken for the feed to move through the reticulo-rumen (Balch, 1950).

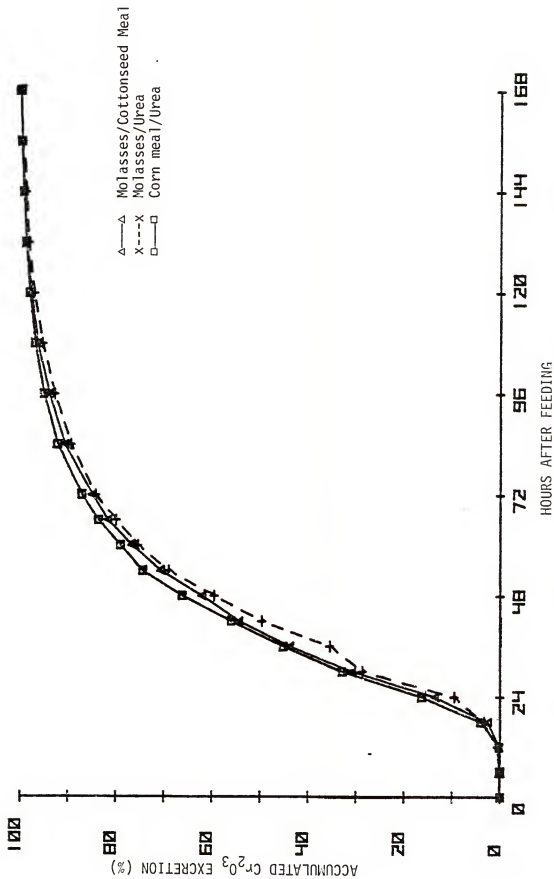


FIGURE 1. ACCUMULATED EXCRETION OF Cr_2O_3 WITH TIME AFTER CONSUMPTION

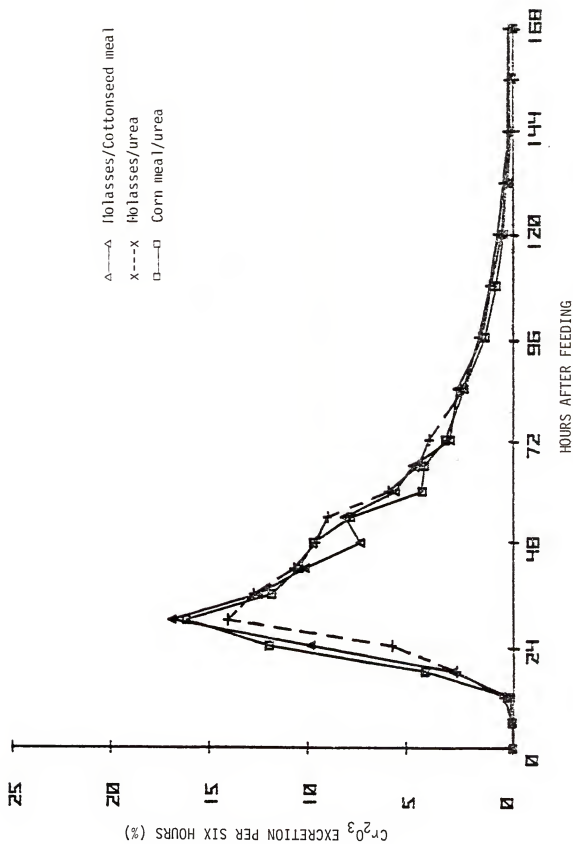


FIGURE 2. EXCRETION PATTERN OF Cr_2O_3 PER SIX HOUR INTERVALS AFTER FEEDING

TABLE 15. MEAN RETENTION TIME, 5% AND 5 TO 80% EXCRETION TIME OF CHROMIC OXIDE OF STEERS FED SUGARCANE BASED DIETS SUPPLEMENTED WITH DIFFERENT SOURCES OF CARBOHYDRATE AND NITROGEN

Variable ^a	Dietary Treatments ^b		
	Molasses/Cotton-seed meal	Molasses/Urea	Corn meal/Urea
Retention, h	38.6	40.1	37.4
5% excretion, h	18.5	18.5	17.4
80% excretion, h	63.6	64.0	62.4
5-80% excretion, h	45.1	45.5	45.0

^a Retention time from Castle (1956); 5%, 80% and 5-80% excretion from Balch (1950)

^b Treatments not significantly different ($P > .05$)

There were no differences ($P > .05$) among the dietary treatments for any of the passage rate parameters, although there was a tendency for steers fed the corn meal/urea diet to have a slightly faster rate of Cr_2O_3 passage than steers fed either the molasses/cottonseed meal or molasses/urea diets. A lack of differences among the dietary treatments shows that rate of passage had no influence on the utilization of the three diets.

The percentage of VFAs in the rumen contents of steers fed sugarcane based diets supplemented with either molasses/cottonseed meal, molasses/urea or corn meal/urea did not vary greatly with the type of diet (table 16 and the probability values are presented in table 17). Propionic acid was higher ($P < .05$) in the rumen contents

of steers consuming the molasses/urea diet than with the other two diets. Acetic acid tended to be lower for steers fed molasses diets than for those fed corn meal, and both valeric and isovaleric acids tended to be higher in the rumen of steers fed molasses than in the rumen of steers fed corn meal. Butyric acid and total VFAs tended to be lower with the molasses/urea diet than with the molasses/cottonseed meal and corn meal/urea diets.

TABLE 16. VOLATILE FATTY ACIDS IN RUMEN CONTENTS OF STEERS FED SUGARCANE BASED DIETS SUPPLEMENTED WITH DIFFERENT SOURCES OF CARBOHYDRATE AND NITROGEN

Acid	Dietary Treatment			SE
	Molasses/Cotton-seed meal	Molasses/Urea	Corn meal/Urea	
Acetic ^a	59.6 ^{cd}	59.1 ^d	62.5 ^d	1.1
Propionic ^a	21.2 ^e	26.0 ^d	20.5 ^e	.7
Butyric ^a	17.9 ^d	13.6 ^d	16.1 ^d	1.2
Isovaleric ^a	.2 ^d	.1 ^d	.0 ^d	.1
Valeric ^a	1.2 ^d	1.2 ^d	.9 ^d	.2
Total ^b	75.4 ^d	70.3 ^d	75.9 ^d	2.3
pH	7.0 ^d	7.0 ^d	6.8 ^e	.1

^a Expressed as molar percentage of the total VFAs

^b Expressed as mM/l

^c Average of 12 observations

^{d,e} Values in the same row with different superscripts are different (P < .05)

TABLE 17. PROBABILITY VALUES OF THE ANALYSIS OF VARIANCE OF THE VOLATILE FATTY ACIDS, pH AND INTERACTIONS

Component	Treatment	Group	Treatment*Group
Acetic acid	.0900	.9979	.5977
Propionic acid	.0001	.0854	.4161
Butyric acid	.0771	.2810	.4385
Isovaleric acid	.1229	.4276	.3315
Valeric acid	.3763	.7218	.9891
Total VFAs ^a	.1944	.1105	.8664
pH	.0324	.9470	.3178

^a Volatile fatty acids

The higher percentage of propionic acid accompanied by a relatively lower percentage of butyric acid with the molasses/urea diet disagrees with most of the studies reviewed by Pate (1983). Butyric acid was reported to increase as acetic acid decreased when molasses was fed with forage based diets. A trend, though nonsignificant, for higher percentages of valeric acid in diets containing molasses agrees with the results reported by Olbrich and Wayman (1972).

A lack of glucose precursors or amino acids at the metabolic level has already been mentioned as factors which could limit production when sugarcane based diets are fed with urea to cattle (Leng and Preston, 1976; Ferreiro et al., 1977). The fact that propionic acid, a glucose precursor, was within the normal range and even higher for the molasses/urea diet ($P < .0001$; table 16) than for the molasses/ cottonseed meal or corn meal/urea diets suggests that lack of glucose or its precursors was not responsible for the tendency for the poorer nitrogen retention or poorer growth of steers fed molasses/urea diet in the metabolism and feedlot trials, respectively. Furthermore, plasma glucose levels were found to be similar for all dietary treatments ($P > .05$) in the present study. The mean plasma glucose levels were 78.5, 81.1 and 84.9 mg/100 ml for the molasses/ cottonseed meal, molasses/urea and corn meal/urea diets, respectively. The tendency for higher glucose levels for steers fed the molasses/urea and corn meal/urea diets than steers fed the molasses/cottonseed meal possibly corresponds to the higher propionic acid in the molasses/urea diet (table 16) and to bypass corn meal from the corn meal/urea diet. A lack of differences ($P > .05$) in plasma glucose levels between the dietary treatments indicates further that glucose or its precursors were not responsible for the variation in the performance of steers reported in this study. Glucose or its precursors

might influence the performance of animals that have high DM intakes above maintenance requirement. As DM intake increases, anabolic processes such as fat synthesis might also increase resulting in an increased demand for NADPH_2 . Since NADPH_2 is produced by both the hexose monophosphate pathway (HMP; from glucose) and the Kreb's cycle (from acetate), diets favoring the production of acetate would reduce the contribution of NADPH_2 from HMP. A reduced supply of NADPH_2 would result in the conversion of surplus acetate (above maintenance) to non-productive heat. During the present study, DM intake above maintenance was less than one half times maintenance requirements for all dietary treatments. Thus, the tendency for a lower ($P > .07$; table 14) nitrogen retention by the molasses/urea fed steers than those fed the other two diets could be due to the lower DM intake ($P < .02$; table 12) which would also result in some metabolizable protein being used as a source of energy. Therefore, an adequate digestible energy intake should be a prerequisite to nitrogen balance studies.

The rumen pH values for the rumen contents of steers consuming molasses/cottonseed meal, molasses/urea and corn meal/urea diets are presented in table 16. The mean rumen pH value for steers fed the corn meal/urea diet was lower than for steers fed the other two diets ($P < .03$). Low pH indicates the presence of high levels of organic acids, and has frequently been associated with high levels of lactic acid (Wilson et al., 1975). Mackie et al. (1978) reported high levels of lactate along with low pH in response to increased concentrates (containing up to 60% maize grain and 10% molasses) in diets fed to sheep. The high pH values reported here are similar to those reviewed by Pate (1983) and appear to be normal for sugarcane based diets.

CHAPTER V SUMMARY AND CONCLUSIONS

A feedlot trial and six digestibility and nitrogen balance studies were conducted to determine the effects of carbohydrate and nitrogen source on the utilization of sugarcane based diets. Molasses and corn meal were the two carbohydrate sources used while cottonseed meal and urea were the two sources of nitrogen tested. The dietary treatments used were: 1) molasses/cottonseed meal, 2) molasses/urea and 3) corn meal/urea, which were fed as supplements to fresh chopped sugarcane diets.

The average daily gains of steers fed the molasses/urea diet during the feedlot trial were lower ($P < .05$) than gains of steers consuming either molasses/cottonseed meal or corn meal/urea diets. Steers fed the molasses/urea diet had a 28% higher ($P > .05$) DM intake to gain ratio than those fed the other two diets. The DM intake was similar for all dietary treatments.

The data from the metabolism trials generally supported the animal performance data on the feedlot trial. Dry matter intake of steers offered the molasses/urea diet was lower than that of steers given the molasses/cottonseed meal diet ($P < .02$), but similar to the DM intake of steers fed the corn meal/urea diet. The digestibility coefficients for DM and organic matter were highest for steers fed the molasses/urea diet ($P < .05$ and $P < .03$, respectively) and was similar for steers fed the molasses/cottonseed meal and corn meal/urea diets. The molasses/urea diet also had the highest digestibility of NFE.

There were, however, no significant differences between diets in the digestibility coefficients of CF, NDF, ADF, cellulose and lignin.

Crude protein or the apparent nitrogen digestibility was lower for the molasses/cottonseed meal diet than for either the molasses/urea or corn meal/urea diets ($P < .03$). Nitrogen digestibility for the molasses/urea diet tended to be lower than that for the corn meal/urea diet. Fecal nitrogen loss was significantly higher ($P < .0005$) for the molasses/cottonseed meal fed steers.

Urinary nitrogen excretion was similar for steers fed all experimental diets ($P > .10$), but steers fed the two diets containing urea tended to excrete more urinary nitrogen than steers fed the diet containing molasses and cottonseed meal. There were no differences ($P > .05$) in the digested nitrogen retained (%) or nitrogen balance data between the dietary treatments. (However, both the digested nitrogen retained (%) and nitrogen balance tended to be lower for steers fed the molasses/urea diet in comparison to steers fed the molasses/cottonseed meal and corn meal/urea diets which were approximately the same.)

There were no differences ($P > .05$) between dietary treatments for any of the passage rate parameters. Relative to rumen VFAs, propionic acid was higher ($P < .05$) in the rumen contents of steers fed the molasses/urea diet than for steers fed the other two diets. The rumen pH of steers fed corn meal/urea diet was lower ($P < .03$) than that of steers fed either molasses/cottonseed meal or molasses/urea. Rumen NH_3 was lower for molasses/cottonseed meal diet than for the other two diets, but the differences were not

significant ($P > .05$). Plasma glucose levels were also not significant ($P > .05$).

(Animal performance was poorer for steers fed the molasses/urea diet than for steers fed either molasses/cottonseed meal or corn meal/urea diets and this appeared to be attributed to an inadequate energy intake above maintenance. Inadequate energy intake might have also reduced the nitrogen retention by steers fed the molasses/urea diet. At similar levels of energy intake, urea and cottonseed meal produced similar levels of animal performance, indicating that urea is nearly as good a source of nitrogen as plant protein when it is fed with a suitable source of energy like starch in corn meal.

In spite of the overall poorer performance of steers fed the molasses/urea diet than those fed either molasses/cottonseed meal or corn meal/urea, the use of sugarcane based diets and urea could be encouraging for developing areas in the tropics. Firstly, data from the present study showed relatively good weight gains (feedlot trial) and positive nitrogen balance (metabolism trials) with the molasses/urea diet which is unlikely with animals fed poor quality hays or forages, as is often the case in most tropical areas. Secondly, sugarcane can be easily produced by limited resource farmers (who are the targets of most research in developing countries) which would make it easier for them to increase cattle production. It would also provide an alternative use of sugarcane to producers who are remote from the sugarcane mills. Thirdly, both protein nitrogen and starchy feedstuffs are scarce and expensive in most developing countries; thus alternative nitrogen and energy sources are important in animal production. Sugarcane, molasses and urea appear to be one answer to

energy and nitrogen supplies for animal production in the tropical regions. The DM intake of sugarcane, molasses and urea based diets needs to be improved.

APPENDIX

TABLE 18. DRY MATTER INTAKE AND FRACTION DIGESTIBILITIES FOR INDIVIDUAL STEERS IN TRIAL 1

Component	Dietary Treatment					
	Molasses/Cotton-meal		Molasses/Urea		Corn meal/urea	
	Steer Number 1	Steer Number 2	Steer Number 3	Steer Number 4	Steer Number 5	Steer Number 6
Dry matter intake, kg	4.9	4.3	5.5	4.2	4.6	4.9
Digestibilities, %:						
Dry matter	66.1	67.0	64.8	68.1	64.1	63.9
Organic matter	66.9	67.7	65.6	69.0	65.4	65.0
Crude protein	57.2	58.0	60.7	64.1	68.1	66.5
Ether extract	54.8	55.6	7.6	50.3	89.8	88.5
Crude fiber	48.2	48.4	43.0	49.9	43.3	43.0
NDF ^a	38.5	41.3	34.4	57.6	40.0	41.1
ADF ^b	43.6	45.1	40.2	43.2	42.0	43.4
Cellulose	52.1	52.2	46.5	50.1	49.6	48.6
Lignin	14.7	17.6	13.8	14.4	18.6	23.1

^a Neutral detergent fiber

^b Acid detergent fiber

TABLE 19. DRY MATTER INTAKE AND FRACTION DIGESTIBILITIES FOR INDIVIDUAL STEERS IN TRIAL 2

Component	Dietary Treatment					
	Molasses/Cotton-meal		Molasses/Urea		Corn meal/urea	
	Steer Number 11	Steer Number 12	Steer Number 9	Steer Number 10	Steer Number 7	Steer Number 8
Dry matter intake, kg	3.9	3.8	3.4	4.9	4.5	3.3
Digestibilities, %:						
Dry matter	65.2	66.6	71.4	68.0	69.2	67.9
Organic matter	66.3	67.3	72.3	69.0	70.5	69.5
Crude protein	60.9	58.6	68.4	66.9	66.1	69.5
Ether extract	65.4	65.8	83.4	54.8	88.8	85.7
Crude fiber	41.0	43.5	52.4	44.2	52.7	49.2
NDF ^a	39.4	39.3	44.8	38.1	45.3	41.3
ADF ^b	40.3	41.5	51.2	41.0	54.4	50.6
Cellulose	44.1	44.9	51.2	41.0	54.4	50.6
Lignin	18.2	21.6	23.5	12.6	35.2	23.1

^a Neutral detergent fiber

^b Acid detergent fiber

TABLE 20. DRY MATTER INTAKE AND FRACTION DIGESTIBILITIES FOR INDIVIDUAL STEERS IN TRIAL 3

Component	Dietary Treatment					
	Molasses/Cotton- meal		Molasses/Urea		Corn meal/urea	
	Steer 3	Number 6	Steer 2	Number 5	Steer 1	Number 4
Dry matter intake, kg	5.5	5.7	2.9	3.6	5.9	4.5
Digestibilities, %:						
Dry matter	61.8	64.8	70.2	70.6	66.4	65.8
Organic matter	62.7	65.7	71.1	71.8	67.6	67.3
Crude protein	53.2	61.1	63.8	60.0	66.7	66.3
Ether extract	62.5	48.0	61.3	34.2	3.5	-66.0
Crude fiber	38.7	42.5	50.0	51.2	46.2	44.1
NDF ^a	33.5	39.6	47.7	48.2	43.2	41.3
ADF ^b	35.5	39.8	45.9	49.4	43.4	47.2
Cellulose	41.5	44.7	49.7	54.1	48.6	47.2
Lignin	14.2	26.8	29.9	32.3	22.8	14.3

^a Neutral detergent fiber

^b Acid detergent fiber

TABLE 21. DRY MATTER INTAKE AND FRACTION DIGESTIBILITIES FOR INDIVIDUAL STEERS IN TRIAL 4

Component	Dietary Treatment					
	Molasses/Cotton-meal		Molasses/Urea		Corn meal/urea	
	Steer Number 8	Steer Number 9	Steer Number 7	Steer Number 12	Steer Number 10	Steer Number 11
Dry matter intake, kg	4.3	4.1	4.7	1.7	4.9	3.5
Digestibilities, %:						
Dry matter	66.2	63.2	65.9	62.4	62.0	64.7
Organic matter	67.2	64.1	67.0	64.0	63.1	66.4
Crude protein	54.9	49.9	60.3	49.2	64.1	66.2
Ether extract	-65.0	-92.3	47.7	23.6	21.7	23.4
Crude fiber	40.7	34.1	47.1	41.5	34.8	43.5
NDF ^a	38.4	33.4	34.6	28.7	32.6	40.1
ADF ^b	42.1	36.9	33.9	27.1	34.7	41.1
Cellulose	50.4	45.6	42.1	37.8	42.0	49.1
Lignin	15.1	12.1	14.4	-10.2	16.0	20.1

^a Neutral detergent fiber

^b Acid detergent fiber

TABLE 22. DRY MATTER INTAKE AND FRACTION DIGESTIBILITIES FOR INDIVIDUAL STEERS IN TRIAL 5

Component	Dietary Treatment					
	Molasses/Cotton-meal		Molasses/Urea		Corn meal/urea	
	Steer Number	Steer Number	Steer Number	Steer Number	Steer Number	Steer Number
	4	5	1	6	2	3
Dry matter intake, kg	4.6	4.9	5.3	5.5	4.1	4.6
Digestibilities, %:						
Dry matter	63.7	68.6	68.8	63.1	68.3	63.5
Organic matter	64.4	69.4	70.6	63.6	69.5	64.9
Crude protein	53.8	57.4	64.9	58.9	62.4	60.2
Ether extract	-58.3	44.5	17.0	-102.0	41.2	26.4
Crude fiber	41.1	52.8	42.7	27.5	49.6	39.6
NDF ^a	35.4	47.2	34.7	26.3	44.3	35.5
ADF ^b	41.1	49.3	43.3	33.4	47.4	40.2
Cellulose	45.8	55.0	48.0	36.1	52.0	43.6
Lignin	22.1	27.6	17.6	12.5	25.0	18.5

^a Neutral detergent fiber

^b Acid detergent fiber

TABLE 23. DRY MATTER INTAKE AND FRACTION DIGESTIBILITIES FOR INDIVIDUAL STEERS IN TRIAL 6

Component	Dietary Treatment					
	Molasses/Cotton-meal		Molasses/Urea		Corn meal/urea	
	Steer Number	Steer Number	Steer Number	Steer Number	Steer Number	Steer Number
	7	10	8	11	9	12
Dry matter intake, kg	5.0	5.6	3.7	3.5	3.4	3.5
Digestibilities, %:						
Dry matter	67.4	58.5	66.6	63.8	59.9	64.3
Organic matter	68.0	59.0	67.2	65.1	61.4	65.2
Crude protein	62.0	53.8	64.8	51.3	57.0	56.7
Ether extract	59.6	44.5	51.6	50.8	56.1	68.3
Crude fiber	43.2	21.8	35.5	40.2	32.6	40.9
NDF ^a	38.1	19.5	32.2	31.6	27.2	38.7
ADF ^b	41.8	21.4	35.5	50.3	30.7	40.1
Cellulose	47.4	28.6	41.4	43.6	37.2	41.6
Lignin	19.9	-6.3	14.6	0.0	8.4	18.1

^a Neutral detergent fiber

^b Acid detergent fiber

TABLE 24. NITROGEN METABOLISM DATA ON INDIVIDUAL STEERS IN TRIAL 1

	Dietary Treatment					
	Molasses/Cotton- meal		Molasses/Urea		Corn meal/urea	
	Steer Number 1	Steer Number 2	Steer Number 3	Steer Number 4	Steer Number 5	Steer Number 6
Nitrogen intake, g/day	80.2	69.5	93.5	70.4	83.2	90.5
Fecal nitrogen, g/day	34.3	29.3	36.8	25.4	26.4	30.2
Apparent digestibility, %	57.2	57.8	60.6	63.9	68.3	66.6
True N digestibility, %	87.8	88.8	90.1	93.8	95.9	93.7
Urinary N, g/day	25.5	19.4	32.9	38.7	28.7	38.2
Digested N retained, %	44.4	51.7	42.0	14.0	49.5	36.7
N balance, g/day	20.4	20.8	23.8	6.3	34.2	22.1
Metabolic fecal N, g/day	24.5	21.5	27.5	21.0	23.0	24.5

TABLE 25. NITROGEN METABOLISM DATA ON INDIVIDUAL STEERS IN TRIAL 2

	Dietary Treatment					
	Molasses/Cotton- meal		Molasses/Urea		Corn meal/urea	
	Steer Number	Steer Number	Steer Number	Steer Number	Steer Number	Steer Number
	11	12	9	10	7	8
Nitrogen intake, g/day	66.3	63.5	61.3	86.4	79.8	56.5
Fecal nitrogen, g/day	25.8	26.3	19.4	28.6	27.0	17.1
Apparent digestibility, %	61.1	58.6	68.4	66.9	66.2	69.7
True N digestibility, %	90.5	88.5	96.1	95.3	94.4	98.9
Urinary N, g/day	22.9	18.1	21.6	39.6	29.3	38.3
Digested N retained, %	43.5	51.3	48.5	31.5	44.5	2.8
N balance, g/day	17.6	19.1	20.3	18.2	23.5	1.1
Metabolic fecal N, g/day	19.5	19.0	17.0	24.5	22.5	16.5

TABLE 26. NITROGEN METABOLISM DATA ON INDIVIDUAL STEERS IN TRIAL 3

	Dietary Treatment					
	Molasses/Cotton- meal		Molasses/Urea		Corn meal/urea	
	Steer 3	Number 6	Steer 2	Number 5	Steer 1	Number 4
Nitrogen intake, g/day	90.3	97.1	45.7	55.1	113.8	87.3
Fecal nitrogen, g/day	42.3	37.7	16.5	21.9	37.9	29.5
Apparent digestibility, %	53.2	38.8	63.9	60.3	66.7	66.2
True N digestibility, %	83.6	90.5	95.6	92.9	92.5	92.0
Urinary N, g/day	32.5	28.6	34.9	28.3	39.0	40.3
Digested N retained, %	32.3	51.9	-19.5	14.8	48.6	30.3
N balance, g/day	15.5	30.8	-5.7	4.9	36.9	17.5
Metabolic fecal N, g/day	27.5	28.5	14.5	18.0	29.5	22.5

TABLE 27. NITROGEN METABOLISM DATA ON INDIVIDUAL STEERS IN TRIAL 4

	Dietary Treatment					
	Molasses/Cotton- meal		Molasses/Urea		Corn meal/urea	
	Steer 8	Number 9	Steer 7	Number 12	Steer 10	Number 11
Nitrogen intake, g/day	70.6	67.2	76.1	25.8	96.2	67.9
Fecal nitrogen, g/day	31.8	33.6	30.2	13.3	34.5	23.1
Apparent digestibility, %	55.0	50.0	60.3	48.5	64.1	66.0
True N digestibility, %	85.4	80.5	91.2	81.4	89.6	91.8
Urinary N, g/day	51.2	28.0	32.2	19.9	29.5	31.2
Digested N retained, %	-31.9	16.7	29.9	-59.2	52.2	30.4
N balance, g/day	-12.4	5.6	13.7	-7.4	32.2	13.6
Metabolic fecal N, g/day	21.5	20.5	23.5	8.5	24.5	17.5

TABLE 28. NITROGEN METABOLISM DATA ON INDIVIDUAL STEERS IN TRIAL 5

	Dietary Treatment					
	Molasses/Cotton- meal		Molasses/Urea		Corn meal/urea	
	Steer	Number	Steer	Number	Steer	Number
	4	5	1	6	2	3
Nitrogen intake, g/day	75.9	80.0	88.7	92.8	69.5	79.1
Fecal nitrogen, g/day	35.0	34.1	31.1	38.2	26.1	31.5
Apparent digestibility, %	53.9	57.4	64.9	58.8	62.5	60.2
True N digestibility, %	84.2	88.0	95.1	88.4	91.9	89.3
Urinary N, g/day	27.5	15.7	23.4	37.1	9.8	19.1
Digested N retained, %	32.8	65.8	59.4	32.1	77.4	59.9
N balance, g/day	13.4	30.2	34.2	17.5	33.6	28.5
Metabolic fecal N, g/day	23.0	24.5	26.5	27.5	20.5	23.0

TABLE 29. NITROGEN METABOLISM DATA ON INDIVIDUAL STEERS IN TRIAL 6

	Dietary Treatment					
	Molasses/Cotton- meal		Molasses/Urea		Corn meal/urea	
	Steer Number		Steer Number		Steer Number	
	7	10	8	11	9	12
Nitrogen intake, g/day	85.7	94.6	62.9	58.5	58.3	56.9
Fecal nitrogen, g/day	32.7	43.7	22.2	28.6	25.1	24.7
Apparent digestibility, %	61.8	53.9	64.7	50.6	57.0	56.6
True N digestibility, %	91.2	83.5	94.1	81.0	86.1	87.4
Urinary N, g/day	17.5	19.7	28.7	22.4	26.8	21.8
Digested N retained, %	67.0	61.2	29.5	25.1	19.3	32.3
N balance, g/day	35.5	31.2	12.0	7.5	6.4	10.4
Metabolic fecal N, g/day	25.0	28.0	18.5	17.5	17.0	17.5

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BIOGRAPHICAL SKETCH

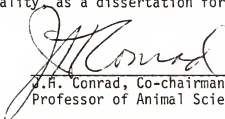
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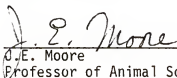
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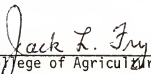
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This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

April, 1984



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